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PROCEEDINGS:

A WORKSHOP ON ISSUES PERTINENT TO THE DEVELOPMENT OF ENVIRONMENTAL PROTECTION CRITERIA FOR RADIOACTIVE WASTES

RESTON, VIRGINIA
FEBRUARY 3-5, 1977

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→ The purpose of the workshop was to address in-depth issues relevant to the development of environmental criteria for all radioactive waste. The question of standards for high-level radioactive wastes was also addressed. Three formal topics were discussed: Approaches to Radioactive Waste Management Criteria Development; Risk Considerations fo Radioactive Waste Management; and Long-Term Implications of Radioactive Waste Management. The information developed will constitute a major input in development of criteria by EPA. This input will be used, together with technical data, to formulate the criteria for radioactive wastes and specific standards for high level radioactive waste.

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A
WORKSHOP
ON

ISSUES
PERTINENT TO THE
DEVELOPMENT OF
ENVIRONMENTAL PROTECTION CRITERIA
FOR RADIOACTIVE WASTES

3-5 February 1977, Sheraton Inn/International Conference Center, Reston, Virginia
Sponsored by the Office of Radiation Programs, U.S. Environmental Protection Agency

This workshop was sponsored by the Environmental Protection Agency to provide the opportunity for additional public involvement in the Agency's process for developing proposals for guidance and standards for radioactive waste disposal. The views expressed by the authors in both their original contribution and in various summarized forms throughout these proceedings do not necessarily represent the views of the Agency, but are those of the participants in the workshop.

A WORKSHOP ON ISSUES PERTINENT TO THE DEVELOPMENT OF ENVIRONMENTAL PROTECTION CRITERIA FOR RADIOACTIVE WASTES*

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* This document is the result of a Workshop sponsored by the Environmental Protection Agency, and held on February 2-5, 1977, in Reston, Virginia.

† These sections of this document were produced prior to the Reston Workshop by the EPA.

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PREFACE

The authority of the Federal Radiation Council to provide radiation protection guidance was transferred to the Environmental Protection Agency (EPA), on December 2, 1970, by Reorganization Plan No. 3. Prior to this transfer, the Federal Radiation Council developed radiation protection guidance which it recommended to the President for use by Federal agencies in developing standards for a wide range of radiation exposure circumstances. In keeping with this function, the EPA, through its Office of Radiation Programs, will develop guidance in the form of environmental protection criteria for radioactive waste to assure protection of the public health and general environment.

In order to provide a means for interested members of the public to participate in the criteria development process, the EPA has arranged to hold a series of public Workshops to address both the long-term implications and risks associated with radioactive waste management and disposal. The first Workshop, entitled "Issues Pertinent to the Development of Environmental Protection Criteria for Radioactive Wastes," was held at the Sheraton Inn/International Conference Center, Reston, Virginia, 3-5 February 1977.

This Workshop was attended by over 250 persons from diverse backgrounds including the general public, government, industry, academies. All who attended the Workshop were afforded the opportunity to participate. The purpose of this document is to record in summarized form the proceedings of the Reston Workshop.

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INTRODUCTION

Radioactive wastes (radwastes) are present in a variety of forms, concentrations, and quantities. These include high-level (HLW) and transuranic-contaminated waste (TRU), both produced through activities associated with military weapons production and nuclear power generation; wastes from medical and dental radioisotopic applications; uranium mill tailings and waste products associated with decommissioning activities; and mining activity wastes, such as phosphate tailings, in which appreciable quantities of naturally occurring radioisotopes are redistributed. While present concern centers strongly about the problem of high-level waste, the criteria and standards to be formulated must address all forms of radioactive waste.

In order to establish the ground rules for the discussion to follow, it is necessary to assign specific definitions to the terms radioactive waste and radioactive waste management. Radioactive waste refers to all retained radioactive materials of no immediate or foreseeable value generated as by-products of man's activities. Management, as used here, is a generic term to describe the entire range of options available as to what to do with the radioactive waste materials and how to implement the selected options. The management options may be divided into two basic categories: storage and disposal. The difference between storage and disposal lies mainly in the degree of institutional control required to maintain isolation of the waste from the biosphere. Isolation through storage will depend upon engineered facilities and institutional activities, while isolation through disposal will be achieved by utilizing the long-term stability of barriers occurring in nature (e.g., deep geologic stata, such as subsurface salt deposits, or seabeds).

There is considerable public concern over the technical feasibility and economic practicability of providing environmentally adequate permanent disposal for all radwastes. Consequently, the United States is faced with an urgent need for a solution to this problem. Key questions arise: How soon can we have acceptable permanent disposal methods for the radwastes already on hand? How effective will those methods be? How much will they cost?

To provide answers to these questions, the development and demonstration of at least one environmentally acceptable method for the permanent disposal of commercial high-level radwastes is essential. The first method may not be the one ultimately or exclusively used, but it should demonstrate that such wastes can be contained in an environmentally sound manner.

Future increases in the amount of various radioactive waste materials in the United States will depend upon the specific

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research policies the country adopts regarding energy production, mineral utilization, research, and other activities. However, regardless of future policies, it may be best to expeditiously find suitable solutions so that disposal of all radioactive wastes can take place in a manner which will ensure adequate protection of the environment and public health.

Currently, a variety of waste disposal methods appear technologically attainable. However, careful consideration must be given to developing the means to evaluate the environmental impacts of the technical alternatives, thus providing a basis for knowledgeable decision-making, to assure that those methods selected for implementation will acceptably meet environmental objectives.

Translating these environmental and public health objectives into practical solutions requires the active participation and interaction of the public, industry, and the responsible Federal and state agencies. Within this framework the U.S. Environmental Protection Agency (EPA) is conducting a program to develop environmental radiation protection criteria and generally applicable environmental standards. In addition to these activities, specific standards and regulations will be developed as required by the Ocean Dumping Act, Federal Water Pollution Control Act, and the Safe Drinking Water Act. The environmental radiation standards (numerical limits) will be implemented by the Energy Research and Development Administration (ERDA) and the Nuclear Regulatory Commission (NRC) through their respective responsibilities in the field of radioactive waste management.

The purpose of "A Workshop on Issues Pertinent to the Development of Environmental Protection Criteria for Radioactive Wastes" was to address in-depth issues relevant to the development of environmental criteria for all radioactive waste. Further, the question of standards for high-level radioactive wastes was also addressed. The information thus developed will constitute one of the major imputs into formal development of environmental criteria by the EPA. This input will be used, together with technical data, to ultimately formulate the criteria for radioactive wastes and specific standards for high-level radioactive waste.

The program provided for a series of formal presentations to identify possible subjects for discussions and then a division of the Workshop into small working groups which strove to develop a consensus on various topics. No relevant subject was excluded nor were the participants required to address any prescribed list of points. Rather, material was prepared and distrubuted to stimulate discussion and then the members of each working group themselves developed in their first sessions an agenda to be addressed relevant to their own topic.

There were three formal discussion topics at the Workshop: Approaches to Radioactive Waste Management Criteria Development; Risk Considerations of Radioactive Waste Management; and Long-Term Implications of Radioactive Waste Management. The sessions were designed to address key issues in each of the above three topical areas from all points of view. The format of the Workshop was kept as informal as practicable, in order to provide for maximum input from all participants.

Most of the first day consisted of a plenary session during which invited speakers provided their opinions on key issues in each of the topical areas. The speakers selected to provide a well-balanced approach. Additionally, members of the public who wished to present a formal statement were allowed to do so, and these presentations are included in this document.

The remaining day and a half was devoted to the small participative working sessions, each addressing a specific topic as described above. Each working group prepared a summary report on their respective issues, including minority or dissenting opinions. These Executive Summaries are included in this document.

This document is a record of the proceedings of the Reston Workshop. The formal papers of the first day (presented in their entirety) are included. The Executive Summaries that were developed in each Working Group at the conclusion of the Workshop, the Issues and Objectives Statements developed by EPA prior to the Workshop, and the response of Workshop participants to the Executive Summaries as elicited in the discussion sessions on the last day of the Workshop are all presented under the appropriate working group topic areas. Prepared statements from the public are presented in a section of their own. Finally, a Summary and Overall Assessment of the Workshop is included to highlight the points that were felt to be of particular relevance to the question of the development of radioactive waste criteria.

SUMMARY AND OVERALL ASSESSMENT OF THE WORKSHOP

The major part of the first day of the Reston Workshop consisted of formal presentations by invited participants. These presentations were, for the most part, fairly general, readily understandable,and representative of the diversity of opinions on factors to be included in criteria, as well as approaches to the problem of development of criteria and standards. The only exception to this were the presentations on the second topic, which dealt more with the technical aspects of risk assessment than with general approaches to the problem.

The first Working Group sessions met at the end of the first day of the Workshop. Generally, the discussions in these first meetings were far-ranging, finally focusing on the problem of identifying points that the group should address on the second day of Working Group sessions.

After the first Working Group session, the moderator and selected participants prepared a list of items to be covered based on discussion held in the first Working Group sessions. This list was presented to each group on the second day of the Workshop, discussed and amended as needed. In its final form, this list was the basis of subsequent Working Group discussion.

A consensus was developed in each working group on many points. Opinions also seemed to overlap somewhat from Working Group to Working Group and are therefore summarized below without specific reference to the Working Group from which they evolved.

1. There was a clear consensus that there is now sufficient information available for the development of criteria and standards and that the EPA should thus begin to develop them immediately. This feeling evolved out of various discussions on disposal methodologies and techniques and out of the fact that a significant waste storage problem is waiting for a solution, i.e., the large amount of high-level waste which has resulted from the weapons program. Along these same lines, it was recognized that to develop one set of criteria applicable to all waste may be difficult. Therefore, the criteria may have to be categorized according to some division based on such factors as concentration, relative hazard, waste form, and/or disposal techniques. No specific recommendation in this regard evolved. Rather, it was simply recognized by the participants that one single overall criterion for all wastes may not be feasible.
2. There was a clear consensus that isolation of high-level wastes in suitable geological formations was desirable. It was further recognized, in this regard, that any repository would remain the period

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when it was receiving the waste. During this period, monitoring should be carried on and assumptions on isolation and storage techniques should be checked. Once the repository is sealed, however, the monitoring should be unnecessary.

3. There was a clear consensus that the radioactive waste disposal method should be independent of the stability of society. The participants felt that it is impossible to predict the future and, therefore, disposal should be carried out in such a manner that isolation from the biosphere would not depend on any society.
4. It was generally felt by the participants that safety of future generations should be a major factor in criteria development. Along these same lines, it was felt that by protecting future generations, we also adequately protect the present generation. Cost was felt by the majority to be of secondary importance to safety, although most felt it could not be ignored. A few did express the opinion that protection of present generations and cost were more important than the protection of future generations. However, it was also generally felt that the costs of the several disposal options presently under consideration were all reasonable. Thus, cost need not be a major concern if we use any of the presently identifinable disposal options.
5. There was considerable discussion about the concept of "zero" release and "zero" dose. Zero was felt by some attendees to be desirable as a goal. However, there was apprehension among other participants who felt that "zero" should not appear in a criteria or standard, since it is impossible to attain. Most participants seemed to agree that the criteria should specify levels of control which isolate wastes from the biosphere for the period of concern.
6. There was a consensus among the participants that criteria should not be keyed to any one method of disposal or form of radioactive waste. It was recognized, however, that forms and methods need to be considered in the formulation of the criteria and standards.
7. There was a consensus among the participants that accidents and unplanned releases should be considered in the formulation of criteria. Furthermore, it was felt that traditional risk analysis techniques which are quantitative in nature should be used to the extent feasible, although with full recognition of the fact that quantitative risk analysis is, at best, an imperfect tool.
8. It was felt by participants that, to the extent possible, criteria should take into account the international implications of radioactive waste disposal. It was recognized that there was little other

that could be done to control the practices of other nations. However, it was felt that it should be clear to all that whatever the United States did should have no safety implications for other nations and thus our criteria could serve as an example for others.

9. The question of acceptability of risk was discussed at great length. This discussion centered around calculated versus perceived risk. Calculated risk was seen as important, although it was strongly felt that perceived risk must also be taken into account when establishing criteria.

10. It was felt by some participants that the risks associated with radioactive wastes should be placed in the context of other risks from similar pollutants or environmental hazards. Further, to the degree possible, the context should be familiar to the public so they can see radioactive waste risks in relation to other risks. It was also recognized that the risks associated with radioactive wastes were in general, better understood, and that the regulations controlling it were more restrictive than for other environmental hazards. Efforts should be made to improve the controls of other environmental hazards rather than relax those on radioactive wastes.

11. There was a clear consensus among Workshop participants that the public, and state and local governments, should be involved in the decision-making process on radioactive waste criteria and other such future regulation and criteria-forming efforts. The clear expression of the group's sentiment was that "the decision-making process should be open in fact as well as in appearance."

The Workshop seemed to achieve its goal of eliciting public concerns about radioactive wastes. A unique aspect to the Workshop process was that groups with diverse and often opposing backgrounds and opinions were able to develop a consensus on certain issues. The net result seemed to be the feeling that the differences were not so great as one might at first have believed.

Despite efforts to the contrary, it was apparent that most of the discussion in this workshop centered around high-level wastes. It was therefore stressed by the participants that the next Workshop should more adequately cover other waste forms, since these disposal problems can be as significant to public health as those of high-level wastes.

Finally, it was clear that public involvement and public acceptance were key points to be considered in any process of setting criteria or standards. The next Workshop should more fully attempt to deal with these questions.

OPENING ADDRESS

William D. Rowe

Deputy Assistant Administrator for Radiation Programs
United States Environmental Protection Agency
Washington, D.C. 20460

Ladies and gentlemen, it is my pleasure to welcome you here today. We appreciate your participation in this endeavor to address in a fully open working forum, public policy issues involved in the development of environmental protection criteria for radioactive waste.

I would like to address three particular areas related to the conduct and purpose of this Workshop. First, I will briefly describe the Environmental Protection Agency's waste management program so you may see how these Workshops and other types of public participation fit into our overall standards-setting program for radioactive wastes. Secondly, I would like to discuss how this workshop will be conducted and how the material developed will be used. Finally, I will address the types of issues in waste management that I think must receive public input.

WASTE ENVIRONMENTAL STANDARDS PROGRAM OF THE ENVIRONMENTAL PROTECTION AGENCY

The Environmental Protection Agency (EPA), through the Atomic Energy Act and the Reorganization Act of 1970, has two basic authorities for setting radiation protection standards that involve nuclear energy activities: (1) the responsibility to set generally applicable environmental standards for radioactive materials or exposures outside the site boundaries of nuclear facilities, and (2) the functions of the former Federal Radiation Council to provide Federal radiation guidance for all radiation directly or indirectly affecting health. In the first instance, EPA promulgated in final form in the Federal Register of January 13, 1977, generally applicable environmental standards for the uranium fuel cycle. These standards (which are to be implemented over the next few years by the Nuclear Regulatory Commission) do not include the disposal of radioactive waste because they were limited to planned releases from the cycle and generally involve the balancing of short-term benefits against similar-term risks.

Waste disposal was excluded from the uranium fuel cycle standard for at least two reasons. First, up to this time the objective of waste management has been that there would be no planned releases to the environment. Second, a different balancing of risks, costs, and benefits is required for waste disposal considerations. Any impacts or risks from the waste

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are likely to occur well past the generation in which the benefits are accrued due to the production of energy. The risks involved, therefore, exist not only for the present generation but also involve deferred risks for many years into the future.

President Ford's message on reprocessing and the export of nuclear technology specifically required EPA to set numerical standards for high-level waste by the middle of calendar year 1978. Our program is aimed at achieving that goal. There are two distinctly interrelated program efforts under way as is illustrated in Figure 1. The first of these is to develop criteria on which to base the standards for waste management. Since we have a new problem in balancing costs, risks, and benefits, we must ask ourselves how should standards be set in the waste management area? For example, what is our objective towards release; are we covered for 100 years, a thousand years, or for how long; what do concepts such as "as low as practicable" mean in this context, what things must be taken into account in setting standards in this area? The issues that we are addressing today can be most easily focused on such questions with respect to developing environmental protection criteria.

In parallel and sometime after the criteria are developed, a technical environmental assessment of high-activity, long-lived wastes will be used within the framework of the criteria to arrive at numerical standards for these wastes. I should note at the outset that many standards the EPA sets will be neither site- nor method-specific. The regulation of waste management operations rests with the Nuclear Regulatory Commission (NRC) whose regulations, when promulgated, will assure that EPA standards are met. The Energy Research and Development Administration (ERDA) is responsible to develop the technology and operate high-level waste sites in conformance with NRC regulations. The Energy Research and Development Administration is also responsible for managing all of the defense-related radioactive waste throughout the country.

WORKSHOP ON PUBLIC ISSUES

The purpose of this Workshop is to begin to address the issues involved in setting environmental protection criteria for radioactive wastes. We hope to elicit maximum participation by all interested parties, including industry, Federal agencies, academia, public interest groups, and members of the general public. An issue paper has been developed by the EPA staff to focus on many of the kinds of issues that we expect to be considered at this Workshop. This document does not profess to cover all issues; further, it has deliberately not tried to provide answers to those issues raised. The main purpose of the issue paper is to identify some topics that ought to be discussed. This is also the purpose of most of this first day. People with different points of view have been invited

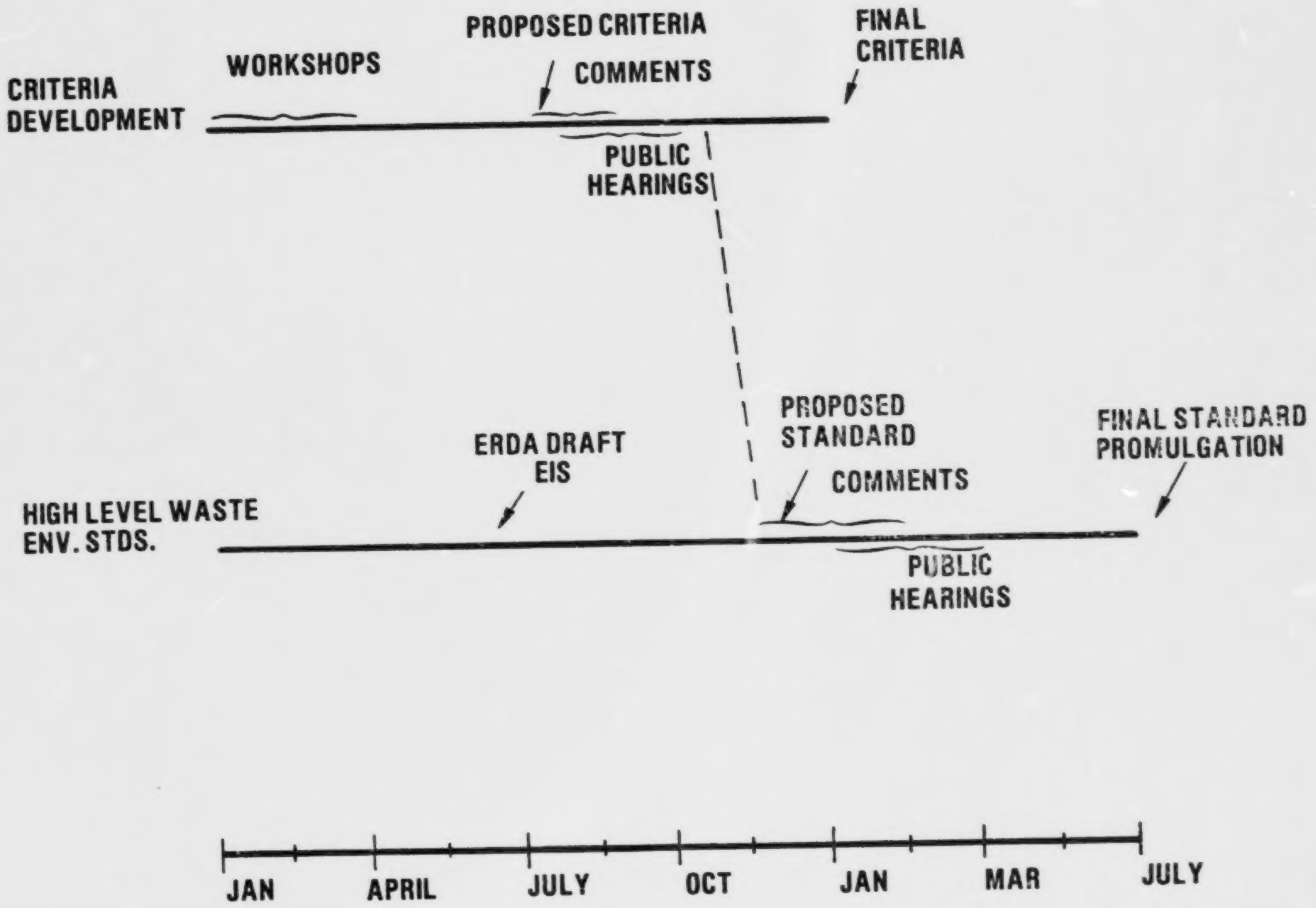

Figure 1. Environmental Protection Agency milestones: environmental standards and criteria for radwaste.

to discuss issues that we ought to be considering as a minimal agenda before we break up into working sessions.

We have also provided an opportunity (in accordance with the announcement) for additional issues and points of view to be developed in written statements. Those received will be presented either in a working session or, time permitting, near the end of the plenary session and, of course, will be published in the proceedings of the Workshop.

The major purpose of the Workshop is to address, in small participative groups, specific sets of issues from all points of view in order to derive suggested approaches for solving these issues. Each working session will have a discussion leader and all attendees of the session will be equal participants. The discussion leader's role is to assure that there is order and that the results are recorded.

Each working session will meet later this afternoon and all day tomorrow. A summary paper on each session's deliberations will be prepared by a small representative committee chosen by the Workshop from volunteers and will include any recommendations or conclusions arrived at by the group. Majority and minority conclusions are expected, since many issues probably will not be resolved to a consensus.

At the last day of the session (Saturday morning) a representative of each working session will present its findings to a plenary session so that everybody may know the results of the various efforts. Further opportunity for discussion will be provided.

ISSUES FOR DISCUSSION

Any issue may be raised before this Workshop as long as it deals with development of environmental protection criteria for radioactive wastes. There are only two issues for which I want to provide EPA's position. One issue is institutional; the other philosophical. First, EPA's role in setting environmental standards for radioactive waste is clear and should, as a matter of policy, not be a subject for consideration at this Workshop. The Agency has established precedents for carrying out its responsibility for such environmental standards in the form of the uranium fuel cycle standard issued on January 13, 1977, and in both specific and general Federal radiation protection guidance. The guidance for uranium miners and recent guidance issued on medical x-rays are examples of the latter.

Although the authority to set generally applicable standards for high-level waste is definitive, the methodologies and rationale are open to input on which questions are pertinent, and suggestions for approach will be given due consideration. An open process such as this is being used for development of

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these criteria and will, we believe, assure that this occurs. We believe that this type of open but formal process in standards is essential for resolution of the radioactive waste problem. The EPA is convinced that the public should be fully aware of the difficulties and pitfalls in such problems and should contribute to understanding of the problem and the development of environmental protection criteria that must be satisfied in its solution.

The second issue involves the need to set environmental standards for wastes versus decisions on further generation of wastes particularly by nuclear power operations. There is no question that considerable amounts of wastes already exist and that these must be disposed of by environmentally acceptable means. Thus, the Agency believes that a program to establish the necessary criteria and standards for such wastes is essential regardless of whether any more are generated. At issue is whether a pragmatic solution for existing wastes should be applicable to future wastes or whether existing wastes should meet the same criteria that may be achievable in the future. In our view, the risks from either should be low enough to be acceptable, especially when those risks are imposed with some degree of inequity. We will not, therefore, cover the question of whether we should stop generating wastes, because we think the problem is sufficient to require early attention on its own. The EPA has no regulatory authority in this area; the question is a broad one and must involve all branches of government. Without diminishing the importance of such a question, I will rule out its consideration at this Workshop, since its discussion here would only be diversion from our major and amply justified task of developing environmental protection requirements for such wastes whether present now or generated later. However, the factors basic to acceptability of risks may be pertinent to this Workshop. Environmental protection requirements should, after due consideration of such factors, be stated and these will then determine how future wastes will be generated and handled according to environmental and public health requirements established in a public process. If future activities can meet these requirements, then the Agency would have no reason to oppose their existence.

All other substantive issues which affect the setting of waste management criteria are fair game. I hope we can go forward with the Workshop with a spirit of identifying all the issues, discussing them openly to get all points of view, defining where different parties agree and disagree, and devising fruitful approaches for solutions.

SUMMARY

To sum up, I hope you will keep in mind that this is our first Workshop for this area and we have a lot to learn; but we sincerely want to provide the best forum we can to obtain public impact before a single environmental protection criterion is drafted. We would welcome suggestions, which I am sure we will get during the course of the Workshop, on how we can better attack such issues with maximum participation. We will certainly try to rectify any findings at the next Workshop, which is scheduled for mid-April in Albuquerque, New Mexico. Thank you.

WORKING GROUP 1

APPROACHES TO RADIOACTIVE WASTE MANAGEMENT CRITERIA DEVELOPMENT

APPROACHES TO RADIOACTIVE WASTE CRITERIA DEVELOPMENT: A STATEMENT OF ISSUES AND OBJECTIVES

Stated briefly, the environmental radiation protection criteria for waste management will be a generalized Agency policy statement detailing the basic philosophy, conditions, and issues that must be considered and reflected in the development of generally applicable environmental radiation standards and in the selection of appropriate waste disposal technologies and sites.

For the most part, the environmental criteria will be quite broad and applicable to all forms of radioactive waste. The generally applicable environmental radiation standards are envisioned as numerical limits pertaining to certain types of radioactive wastes such as high-level radioactive waste. However, both the environmental criteria and generally applicable environmental radiation standards will be neither site-nor method-specific.

BASIC PHILOSOPHY FOR ENVIRONMENTAL CRITERIA

The overall goal of EPA with respect to radioactive waste management is to minimize the adverse health impact to present and future generations as well as to minimize degradation of environmental quality. In its efforts to attain this goal, its actions to date have been based upon the philosophy that proper waste management is the containment or isolation of radioactive waste materials until they have decayed to "innocuous" levels. In this context, containment or isolation may involve burial, storage, or some other form of assurance that intolerable dispersion into the biosphere does not take place. Continuation of this philosophy appears logical unless it can be satisfactorily demonstrated that selected alternatives (such as certain forms of dispersal to the environment) would result in less total environmental and public health impact. If this could be shown, the premise of containment for all wastes might be unnecessarily restrictive as a basic philosophy in criteria and standards development and could require modification. This question should be considered before the philosophy of the criteria is established.

The development of environmental criteria will have to consider several philosophical issues, including acceptable risk and how to determine it, the question of the legacy of radioactive wastes due to their long lifetime, and to what extent emphasis should be given to minimizing long-range impact, potentially at the expense of immediate impact or vice-versa. Each of these issues has many facets which may require consideration to differing degrees. If environmental criteria are to be meaningful, it is necessary that substantial input and discussion be focused around basic philosophical issues in order to provide a sound foundation for public policy and action.

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Another important factor to be weighed in selecting radioactive waste disposal technologies and sites is economic cost. While this may appear to be a practical consideration, it also strongly relates to the philosophy upon which environmental criteria and generally applicable numerical radiation standards would be based. For example, should environmental and public health protection be fundamental, with cost of disposal a secondary consideration to be examined after technologies which would result in acceptable radiation protection have been identified? Is cost consideration as important as environmental protection, with both factors to be considered simultaneously in seeking a reasonable balance between the two?

Recognizing that less expenditure may result in less public health assurance, perhaps the appropriate philosophy would be to establish a minimally acceptable level of radiation protection for any disposal of radioactive waste. Resource expenditures necessary to achieve this level should then be accepted by society. Once this is attained, increased protection could be obtained to the extent practically and economically achievable. As a result of the numerous alternatives available in dealing with cost-risk evaluations, the specific degree to which cost-effectiveness should form the philosophy for environmental criteria, standards, and disposal technologies must be clearly delineated.

Further, perhaps it is advisable for the environmental criteria to provide guidance on how to utilize cost-effectiveness in the development of standards and disposal alternatives. Guidance might include recommended values for the worth of averted health effects such as $100,000 to $500,000 per health effect, or at least a methodology for evaluating such worth. Further, it might include suggested methodology for uniformly evaluating cost-benefit or cost-risk.

PRAGMATIC CONSIDERATIONS

Once the philosophical bases for the environmental criteria have been established, it becomes necessary to translate the philosophy to practical conditions for the development of generally applicable environmental radiation protection standards and the selection of appropriate technological methods and disposal sites. It is anticipated that acceptable radioactive waste disposal should be achievable through the combined use of techniques involving waste processing; containerization; engineering controls in site selection, construction, and operation; judicious use of carefully selected environmental barriers such as geological strata; and preplanned monitoring programs and emergency response procedures.

While the environmental criteria should not be site- or method-specific, the conditions and policy positions they establish should be definitive guidance as to which aspects of waste disposal are considered of primary importance from the standpoint of public protection. The criteria may require definitive policy positions on aspects such as:

1. The retrievability of the waste over the short- and the long-term.
2. The relative importance of environmental barriers such as geological strata versus engineering controls such as containers.
3. Requirements for long-term care.
4. The need for preplanned emergency response procedures and monitoring.
5. Methodology for estimating and quantifying potential environmental and public health impacts.
6. Compatibility of disposal techniques with various types and forms of radioactive waste.

Clearly all of the topics for consideration in the development of criteria conditions are not limited to those listed above. It is anticipated that open discussion of such topics and others will lead to selecting those of primary public health, social, political, and economic importance which will provide for government and industry the information base to achieve public health protection from radioactive wastes.

In dealing with the long-term management of radioactive wastes, standards as implemented to date may not be entirely applicable. The equivalent of routine releases is not necessarily the major problem of concern as much as the potential for unplanned events (both man-made and natural) which could alter the functioning of the respository in such a way that large-scale releases to the biosphere might occur. The uncertainties regarding long-term institutional stability may preclude placing reliance on remedial action to recover from such an incident many years in the future.

To circumvent this problem, a possible approach could be the promulgation of what may be referred to as "Radiological Impact Limitation Guides (RILG)." The differences between the concepts of these guides and the present form of standards are subtle but real, and the distinction should be made. The guides would apply basically at the design and implementation stages of waste management facilities to assure that the conditions described in the RILGs, i.e., the minimally acceptable upper level radiological impact limit, will be satisfied over the entire lifetime of a repository, and to assure that a repository will be designed in such a way as to accommodate, into perpetuity, all conditions and potential intrusions without dependence on the existence of institutional capability to cope with such situations. In this way minimum reliance on future institutions would be necessary. However, higher economic costs may result from attempts to provide such assurance.

SUMMARY OF CONSIDERATIONS

This section has addressed issues, topics, considerations, and approaches that could be used in developing and establishing environmental radiation criteria for radioactive waste management. It does not necessarily reflect all topics or approaches but rather is designed to facilitate discussion and evaluation. Questions which focus on these issues, considerations, and approaches are listed below to stimulate in-depth discussion:

1. Can and/or should environmental radiation protection criteria be established on a generic basis addressing all forms and types of radioactive wastes if possible?
2. For what kind of wastes or what conditions might generic criteria not apply? How could these best be addressed?
3. To what extent should the Agency's basic waste management philosophy espouse containment or isolation until decay to "innocuous" levels? Can such a philosophy be used for all radioactive wastes?
4. How should the criteria consider risk? Should the Agency recommend methodology for risk evaluation?
5. Should the criteria establish umbrella-type limits on planned individual and population risks, both for present and future generations? Standards would probably then reflect these risk limits as numerical dose or release values. Should the criteria contain an assessment of planned risks to individuals and the population by the most probable release modes?
6. How should the criteria consider legacy? Are instabilities of institutions paramount in this consideration?
7. What are the trade-offs between the impacts on present, near-future, and far-future generations from radioactive wastes and from waste management decisions made in the present? Is environmental and public health impact to present, near-future, or far-future generations most important in criteria and standards development?
8. How should cost-effectiveness be considered in the basic philosophy? Is public health protection of greater importance than cost? Should a minimum public health protection level be established regardless of cost? Is geologic disposal too expensive? Is it the only practical approach at present?
9. Should the criteria provide guidance on how to perform cost-effectiveness and/or benefits versus risk evaluations? Should a value for health effects averted be established?
10. How can criteria and standards factor in both the normal and "accidental" impact factors?
11. Should waste retrievability be maintained for some time period? For how long and at what cost?

12. What is the relative importance of environmental barriers such as geological strata versus engineered barriers such as containers and waste form?
13. How should long-term care and monitoring be planned or is it necessary?
14. Should the availability of remedial measures in the event of an accident be preplanned or, because of potential institutional instabilities in the future, should this approach be avoided?

APPROACHES TO CRITERIA DEVELOPMENT

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Issues related to management of radioactive wastes as perceived by many members of the public and spokesmen for special interest groups currently represent a major obstacle to more generalized public acceptance of nuclear power. There is no question that we have already produced substantial quantities of radioactive waste materials, that production of radioactive wastes is inherent in the nuclear power fuel cycle, and that questions related to these materials must be resolved.

The management of existing radioactive waste accumulations and a wide variety of waste streams in the gaseous, liquid, and solid state which involve a broad spectrum of radioactive material and chemical characteristics is obviously required. Implicit in the term "management" is the requirement of acceptability in terms of public health protection and environmental quality. In this context there are two major points. First, defining acceptability of risk to radiation exposure in some quantitative fashion and, similarly, defining acceptable levels of environmental quality is required. Second, the physical means for treating, processing, or otherwise handling the waste materials in ways that the defined levels of acceptability are met is necessary. From these two basic requirements evolve the broad variety of scientific, technical, economic, social, and institutional issues that relate with varying degrees of importance to the subject of radioactive waste management.

The announcement of this Workshop stated that the Environmental Protection Agency (EPA) intends to develop environmental protection criteria and standards for radioactive wastes to insure protection of the public health and general environment. Further it states that EPA will concentrate on "general protection criteria for all radioactive wastes and a specific numerical standard for high-level, long-lived radioactive wastes" from the nuclear fuel cycle.

The Issues and Objectives Statements prepared by EPA for this Workshop also state that "the Agency's overall goal with respect to radioactive waste management is to minimize degradation of environmental quality." They further state

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that "its actions to date have been based upon the philosophy that proper waste management is the containament or isolation of radioactive waste materials until they have decayed to 'innocuous' levels."

In this connection it is believed important to examine briefly at the outset some significant implications of these statements, particularly as they relate to the long-term aspects of management of radioactive wastes. In examining the issue of long-term potential risk associated with the storage/disposal of radioactive wastes, including high-level wastes in geologic formations, the central consideration is not so much the specific longevity of the wastes or their constituents as it is the potential mode or pathway of exposure risk for the population or an individual at any point in time. The nature of the risk of exposure via a particular pathway is related to factors of quantity and concentration of radioactive material and, of course, to time as it affects these factors. However, pragmatically one might just as well consider the very long-lived radioactive materials, the transuranics, as stable (like arsenic or mercury). In simple terms the objectives of radioactive waste management are:

1. To assure that populations are adequately protected in relation to their air, water, and food supplies.
2. To assure that individuals (intruders) who might somehow come in contact with the disposed materials are adequately protected.

In the former case, for essentially all the waste streams of concern (with the exception of pure, very long-lived materials), the situation is clearly dominated by the fission product content--more specifically by strontium-90. One must be assured that there is sufficient containment in the system so that if or when the material does get into air, water or food supplies, the concentrations of the critical radionuclide (strontium-90) will be within acceptable levels.

After about 300 to 400 years (with the hazard to air, water, and food supplies reduced by two or three orders of magnitude) the transuranics are controlling. However, it is difficult to see how, if it can be concluded that the disposal system provides the degree of protection to the public for the few hundred years required for the fission products, more rapid transport and dispersal of the disposed material could take place without involving tremendous amounts of dilution, energy, time, or all three in a way that would result in unacceptable concentrations of radioactive material in air, water, or foods. In essence, this first objective is, comparatively speaking, short-term and relates to the quantity of disposed fission product material available for potential transport and dispersal, and the specific characteristics of the transport and dispersal mechanisms and pathways.

With regard to the second objective, assuming contact with the waste by a single (or a few) individuals is prevented for the few hundred years noted above, the protection requirements of the disposal system are then controlled by the very long-lived radioactive material and, as noted earlier, we might as well consider their longevity as though they were stable materials. We are now concerned with assuring that the individual intruder coming in contact with the disposed material will not take in unacceptable amounts of the material through inhalation or ingestion. This is related entirely to the concentration of the very long-lived constitutents in the disposed material. If small quantities of the disposed material, which might be ingested or inhaled by an intruder, would result in unacceptable doses; i.e., high concentrations of the long-lived constituents, then a high degree of isolation--not containment--(for practical purposes forever) would be necessary. Hence, the motivation for disposal in geologic formations such as bedded salt, which have been in place for geologic periods of time.

In the above comments a distinction is made between "containment" and "isolation." Containment means keeping the radioactive material within defined confines of whatever place the material is put. Isolation means selecting a place where it would be hard to intrude accidentally upon the material disposed there. In connection with the first objective identified above, absolute containment is not required. It does require, as indicated, a degree of containment high enough so that any movement of radioactive materials from the location of disposal will be small enough and slow enough that, as stated, if and when the radioactive material does get into air, potable water supplies, or food supplies, the concentrations of all radioisotopes will clearly be within acceptable levels.

Therefore, in general terms we have this two-faceted situation--protection of air, water, and food supplies of populations, which involves the inventory or quantity of fission products (strontium-90) with a time-frame of a few hundred years, and the protection of individual intruders from ingesting or inhaling unacceptable quantities of material, which involves the concentration of very long-lived constituents in the disposed material with a time-frame comparable, for practical purposes, to that associated with stable toxic materials, i.e., of no material significance in assessing the risk to potential overexposure. Incidentally, it might be pointed out that when considering the question of protection of individual intruders against the very long-lived constituents the limiting levels would be significantly higher than for protection of populations against the fission product (specifically strontium-90) content.

With respect to the general protection criteria for all radioactive wastes it would be useful to elaborate on the description and quantification of levels of releases from radioactive waste sources associated with the range of activities listed in the Introduction of the Issues and Objectives Statements prepared by EPA for this Workshop. Specifically, wastes from weapons manufacturing, military propulsion systems, research laboratories, hospital facilities, commercial isotope production as well as the operations comprising the entire nuclear fuel cycle might well be amenable to the development of an impact ranking similar to that of health effects associated with major radiation sources that EPA has developed. Such an elaboration would presumably focus on what waste treatment is currently being applied or is planned, the risk of adverse effect from waste releases, the costs of control by source of waste, the benefit of the source, and the benefit to be derived from incremental levels of control. This kind of analysis would serve to put the various facets or segments of the radioactive waste picture in perspective as well as elucidating the relative risk and potential for public risk reduction in each area. One might also consider including naturally occurring radioactivity levels in drinking water in such an analysis since, at least theoretically, they are potentially amenable to reduction.

Again within the context of general environmental protection from all radioactive wastes, it would seem that a reasonable approach or first cut could be quite similar to that taken by EPA in its promulgation of Part 190-Environmental Radiation Protection Standards for Nuclear Power Operations.

Without attempting here to determine or justify a numerical value of annual dose equivalent to a member of the public not to be exceeded as a result of waste management operations (some reasonable increment to the 25 mrem/year of Part 190 might be one suggestion), such an approach would serve to significantly facilitate the current phase of federal agency waste management programs. The requirement to assure that this limit is not exceeded over an extended period of time is, of course, recognized. This includes the need for analyzing long-term dose commitments and, where deemed necessary, for the Energy Research and Development Administration (ERDA) or the Nuclear Regulatory Commission (NRC) to base control requirements on the results of such analyses. The minimization of adverse health impact noted in EPA's overall goal with respect to radioactive waste management previously alluded to is directly related to the ALARA (As-Low-As-Reasonably-Achievable) approach which is currently integral to the NRC's regulatory function. It would appear that the application of ALARA would be logically carried out by NRC in its development of specific operational guidance or standards.

This approach is also believed to be consistent with the responsibility assigned to EPA under the President's Reorganization Plan No. 3, under which EPA was established and with EPA's statement of its Radiation Protection Program Strategy and its Development Plan for Environmental Protection Criteria for Radioactive Waste Management.

Since EPA has a responsibility for overall environmental radiation impacts and effects, it is logical that it supply the broad quantitative guidance to other agencies on the overall allowable levels of radiation in the environment consistent with acceptable risk to the population. This involves large-scale national and international criteria and/or standards designed to protect against national or world-scale buildup of long-lived radioactive products in the ambient environment. Such concern for potential long-term impacts of environmental radiation might be considered as an important focal point for EPA's basis for setting overall environmental criteria for radiation protection. The general strategy suggested by EPA, "to focus in order of priority on controlling exposure to those radiation sources that present the greatest actual or potential risk for adverse health effects to the population," is reasonable. The guidelines for implementation of that strategy need to be more systematic and quantified, and it is in that context that the need noted earlier for the elaboration of the description, quantification, means for and level of required control, etc., for all radioactive waste sources is believed important. This importance is reflected in EPA's listing of estimated potential health effects associated with major sources of radiation. Of the annual total of 10,224 health effects (excluding natural background and including 8,000 from the healing arts, 1,000 from construction materials, 800 from weapons, 200 from consumer products, 100 each from air travel and occupational exposure) only 24, or slightly over 0.2 percent are estimated to be associated with the nuclear fuel cycle for power generation. From this tabulation there clearly arises the question of relative emphasis being placed on Federal radiation protection efforts and programs.

The second subject area covered in this Workshop--namely, a specific numerical standard for high-level, long-lived radioactive wastes--should also be considered in the light of the above tabulation. It is indicated by EPA that nuclear power is a small fractional source of potential radiation risk and there are analytic indications that high-level wastes from commercial nuclear power are likely to be but a fraction of the source of radiation exposure associated with radioactive wastes overall. Again, the question of relative emphasis on radiation protection programs is raised.

Before getting into approaches to criteria and standard development in the area of high level wastes, it might be well to recount in simplified fashion the institutional framework within which the criteria, standards, etc., are being addressed and by whom. For present purposes the institutional framework is somewhat narrowly defined as the major federal agencies having assigned responsibilities and authorities relating rather directly to management of high-level wastes. The government policy as described in the White House Fact Sheet released October 28, 1976, is probably as good a basis for such definition as any and specifically indentifies ERDA, NRC, and EPA as having specific roles in the "President's Nuclear Waste Management Plan" and time lines for accomplishing their assignments, all culminating in "initial commercial-scale operation" of a federal high-level waste repository in 1985. In separate actions not under the "President's Plan," ERDA also plans to have a waste repository for defense wastes in place by 1983. While other federal agencies such as U.S. Geological Survey, U.S. Coast and Geodetic Survey, and Bureau of Land Management, will undoubtedly be involved in the program in one way or another, and perhaps importantly with some specific guidelines, criteria, or standards, their detailed participation need not concern us for the moment.

As currently reflected in the federal commercial high-level waste management program, ERDA has the responsibility for the research, development, and testing for the high-level waste solidification, packaging, transport, and emplacement in a federal repository. It also has the job of locating, designing, constructing, and operating the federal repository. Although all detailed decisions may not yet have been made, it is reasonably clear that the commercial high-level waste management system being implemented in this program consists of solidification (calcination and/or vitrification) of high-level liquid wastes, appropriate packaging, transport, and emplacement in a deep halite (salt) formation. In light of the current uncertainty regarding spent fuel reprocessing, the capability of handling spent fuel in the repository obviously must also be an integral part of this program. This would entail among other things appropriate consideration of the effect of larger quantities of plutonium contained in the disposed material.

The NRC has the job of "licensing" this system. Licensing is in quotes only because at present it is not quite clear as to the procedures by which such a licensing process will be carried out.

The EPA is indicated as having the responsibility of this year, i.e., 1977, to "draft generally applicable standards for permanent storage of high-level wastes," and by mid-1978 issuing "final general ambient standards for high-level waste disposal."

It is apparent then that ERDA will have to be engaged in developing a broad variety of guidelines, criteria, standards, and specifications in order to assure that the entire system performs in accordance with design specifications. The NRC somewhat similarly will have to develop a set of guidelines criteria, standards, etc., as a basis for "licensing" the system, i.e., presumably the bases for concluding that it can, or cannot, be located, built, and operated "without undue risk or hazard to the public." The EPA in effect defines the environmental levels of radiation that might be considered as equivalent to "without undue risk or hazard to the public."

In addition, ERDA must prepare its general and specific environmental impact statements and NRC has to prepare its environmental impact statement. The EPA has a responsibility for reviewing and commenting on the environmental impact statements. The EPA in its preparatory paper recognizes the significance of economic costs in relation to the environmental criteria and generally applicable numerical radiation standards. This recognition suggests that it might be appropriate for EPA to prepare an economic impact statement in connection with its proposed criteria and standards.

There are, of course, a wide range of specific issues related to a specific high-level waste management system for which suitable (i.e., acceptable) criteria must be developed by ERDA and/or NRC. A brief and certainly not all-inclusive listing serves our current purpose.

1. Waste Solidification Facility (WSF):

    a. Secondary waste stream D.F. requirements, ALARA requirements for WSF
    b. Solid waste product specifications--leachability, thermal stability, temperature limits, etc.

2. Packaging:

    a. Package specifications-canister size, temperature limitations, heat density, shock resistance, secondary containment requirements, etc.
    b. Design considerations-stress imitations closures, leak detection, QA requirements, accident considerations.

3. Transport:

    a. Cask design and operational requirements--shielding, heat dissipation, shock resistance, weight-size limitations.

4. Repository:

    a. Site selection and approval criteria--geophysical, environmental, demographic
    b. Environmental and safety assessment--bases, models, allowable levels
    c. Design basis accidents
    d. Operational criteria and standards--halite formation temperature limitations, ALARA requirements, retrievability requirements, surface land use criteria.

Within the institutional and issues framework briefly described, the role of EPA and its approaches to criteria development relative to high-level waste is addressed.

First of all, it is pertinent to differentiate between EPA's criteria/standards setting role and its review/comment/advise/compliance role. With respect to the former, it seems reasonable to suggest that an approach quite analogous to that previously noted for the overall waste picture would be in order. That is, an equivalent annual dose limitation to persons and populations outside the control of the facility could be applied to the management of high-level wastes. The application of the ALARA philosophy could be carried out as previously noted. Indeed, in a quantitative sense the values for high-level waste management might well be included under the umbrella developed for the overall waste picture. Adherence to these standards and application of ALARA would then be a question of compliance by ERDA and NRC in carrying out their location, design, construction, operation, and licensing functions.

With respect to the latter review/comment function, EPA should not require completely independent detailed pathway/dose/risk assessment models and analytical methods. While EPA might well need the capability to examine the validity of various assumptions and bases inherent in assessment models and analytical methodology, it seems reasonable to suggest that this function, and the development of appropriate models, can most effectively be discharged through a preferably formalized, coordinated interagency effort. Such a coordinated interagency effort would also ensure timely resolution of philosophical or methodological differences. This is particularly important in the development of appropriate models and their application to potential long-term impacts.

Another point related to the long-term cost-benefit aspects of the generation of commercial nuclear wastes is that the benefits derived from nuclear power generation include, among other things, not only the conservation of our coal and hydrocarbon resources for future high-value use, but also the reduction of wastes resulting from the combustion of these resources. Accordingly, long-term cost or cost-benefit assessments of wastes from commercial nuclear power should include consideration of the long-term cost associated with equivalent fossil fuel use, i.e., the CO_2, SO_x, NO_x, heavy metals, and solid wastes.

Finally, I would state the strong conviction that we have the capability to establish nuclear waste management systems that can and will protect the public health and our environment. It sorely behooves us to take the implementing actions, both technically and administratively, and get on with the job in an expeditious and effective manner.

GEOLOGIC ASPECTS OF CRITERIA DEVELOPMENT FOR RADIOACTIVE WASTE MANAGEMENT

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My background is in geology, and my comments in this paper will be directed to geological considerations involved in establishing criteria for radioactive waste management. Geology affects the setting of criteria in two principal ways: first, by providing data on natural background radiation; and second, by giving a basis for judgment about the certainty of containment of radioactive waste in disposal sites.

The radiation from waste, dangerous as it may be, is only an augmentation of natural radiation to which we are all expsoed every day of our lives. This fact is widely known, but often not sufficiently emphasized. The kinds of radiation are the same, and the effects on organisms are the same. In seeking to reduce waste-generated radiation to a minimum, we are not dealing with a new and necessarily evil product of technology. We are rather trying to control a gross increase in one of the factors in our natural environment. In setting standards for acceptable limits of exposure, we cannot hope to reduce radiation below natural levels.

Natural levels prove to be very diverse. Radiation in our environment comes from many sources: cosmic rays from outer space; radioactive elements widely distributed in rocks, soil, and water; and radioactive carbon and potassium in our own bodies. In civilized society these are augmented by radiation used in medical and dental diagnoses and treatments, and minor amounts from television sets, luminous watch dials, and air travel at high altitudes. Exposure of individuals to all these sources varies widely from time to time and place to place. The average individual exposure to purely natural radiation in the United States, for example, is about 130 millirems (mrem) per year, but fluctuates within about 15 percent of this figure at any one place. The amount varies over the country from an average of 250 mrem/year for Colorado and Wyoming to 100 mrem/year for Louisiana and Texas. The amount of medical and dental radiation obvicusly varies greatly from one individual to another. People who live in brick or stone houses receive about 40 mrem more per year than those whose houses are made of wood, because of the traces of radioactive elements in such materials. Individuals in certain types of occupations receive much more radiation exposure than the average person: crew members of high-altitude jet aircraft, for example, are exposed to an average of 670 mrem/year, and uranium miners are exposed to considerably more.

There is not the slightest evidence that those exposed to the higher levels of natural radiation are thereby harmed. That harm is actually done but is not apparent in the statistics is possible. On one side are those who feel that any radiation whatsoever is harmful, and that the lack of evidence merely reflects difficulty in obtaining statistics about small effects in large populations over long periods. This argument depends on extrapolation from data on the very damaging effects of large doses of radiation. If, for example, the probability of dying from cancer is 20 percent after exposure to 1 million mrems of radiation, the probability after exposure to 100 mrems would be 0.002 percent. The validity of such an extrapolation is not known. On the other side of the argument are those who question the extrapolation on the grounds that human beings have lived in the presence of low-level radiation for something like 3 million years, and that living tissue is well known to be capable of repairing damage that may occasionally be done by brief exposure to low-level radiation. The argument is impossible to settle on the basis of present knowledge. Conceivably humankind would suffer fewer ills if people could live in a completely radiation-free environment, but this is a hypothesis that would be very difficult to prove.

From a geologic point of view, the hypothesis that very low-level radiation is harmful seems strained. A geologist is acutely aware of the extreme differences in amounts of the radioactive elements uranium, thorium, and potassium contained in different parts of the earth's crust, and also of the extraordinary adaptability of organisms to their surroundings. He can look back over the 600 million years during which higher organisms have evolved, and note that at the beginning of that time radiation on the earth's surface was considerably more intense than it is today. He may even wonder whether radiation in small amounts might not actually be beneficial to living things, since they have evolved in its presence. But clearly again this is another unsubstantiated hypothesis.

The constant presence of natural radiation in widely varying amount makes the setting of criteria for radioactive waste management very difficult. Ideally, we could set up a "zero-release" criterion, requiring that waste should be so effectively isolated that it could make no addition to natural radiation. But what level of natural radiation: The average for the country, the amount in the immediate vicinity of the disposal site, or the higher intensities characteristic of some large areas? Does a zero-release requirement make sense when slight additions to the ambient radiation would not bring the total even close to amounts characteristic of some parts of the country where the population shows no ill effects? These are questions that have no scientific answer, because the data on which an answer could be based are lacking and will be lacking for a long time to come. Prejudice based on geologic orientation would suggest a fairly relaxed criterion, to the effect that radiation from wastes should not be permitted to increase the total radiation exposure in a given area to more than some of the higher natural values, say 200 or 300 mrem/year to an individual. But this geological bias must be weighed against prejudices of many different sorts.

The second way in which geology can have a bearing on the establishment of criteria is in evaluating the probable effectiveness of various proposed methods for long-term isolation of radioactive wastes from the biosphere. A geologist is more accustomed than most to thinking about the long time periods, up to at least a few hundred thousand years, during which the wastes must remain isolated. Perhaps just for this reason--because of his intimate acquaintance with the kinds of geologic disturbances that can occur in such long intervals--he is more cautious than many in making pronouncements about the absolute safety of any disposal method.

The suggested method currently in greatest favor for handling high-level wastes involves solidification of liquids and burial of the resulting solids in caverns excavated in rock at depths of 300 to 1,500 m. Such burial sites would be subject to the usual kinds of geologic calamities--exposure by erosion, and disturbance by earthquakes or volcanic activity. A geologist can give almost complete assurance against this sort of occurrence simply by recommending sites where erosion over the next million years will be slow and where rocks and rock structures indicate that earthquakes have been minor and volcanic eruptions nonexistent for a long time in the past. The greatest danger is none of these, but the possibility that groundwater may penetrate to the entombed waste, dissolve some of the radionuclides, and transport them to the surface. Once they reach the surface, the radionuclides can contaminate drinking water, be taken up by food plants and animals, or become part of soil and dust to be transported by wind. The picture of active radionuclides flowing to the surface in large quantities from a breached bedrock cavern can be made to look very grim.

No geologist can make a firm statement regarding the possibility of some leakage from underground storage in the course of a million years. However secure a given site may look at present, changes in climate, minor rock movement, or human activity might conceivably permit access of water. Current thinking favors salt, either bedded or in domes, as material in which waste could be most safely disposed, on the grounds that salt has desirable mechanical and heat-conduction properties as well as great impermeability to water. Another promising material is shale, also known to be highly impermeable. Some kinds of crystalline bedrock--carbonate rock, granite, basalt--are also under active investigation. It seems probable that all of these materials, in carefully selected localities, will prove suitable for waste disposal. If this is true, a multiplicity of disposal sites consisting of different materials and in different parts of the country might be preferable to a single site. Large numbers of sites would be advantageous in that only a small amount of waste need be placed in each one, so that even an unforeseen catastrophe could not lead to contamination of a large area. With regard to selection of sites and probabilities of groundwater contamination, a geologist can give good advice, but he can never state categorically that no leakage whatever will occur from any given place.

Suppose that groundwater does reach an underground disposal site and then percolates through rock to emerge in a seepage some kilometers distant. What would be the consequences? In this situation, a geologist can speak with more assurance. He knows the rate of groundwater movement under various conditions, and he would surely have selected the site at a place where movement was slow, say a few centimeters per day at the most. He would also have chosen a site where any conceivable path of movement to the surface would be long--certainly tens of kilometers. This means that any water that had been in contact with waste would not reach the surface for hundreds of years at a minimum. The solid material in which the waste was incorporated (glass or ceramic) would be extremely insoluble, so that leaching of the radionuclides would be slow. The ions that did get into the moving groundwater would be, for the most part, absorbed on mineral surfaces in the rocks through which they move. Actual measurements at Hanford show that the most dangerous of the fission products (strontium-90 and cesium-137) would move at least a hundred times more slowly than the groundwater because of absorption, and plutonium at least 10,000 times more slowly. Thus a geologist can say confidently that a little groundwater and a tiny amount of radioactive material might conceivably reach the surface in the course of a million years, but that a massive movement of radionuclides from the disposal site is all but impossible.

We therefore come back to the question of how much addition to ambient radiation would be tolerable. Disposal of waste in bedrock can be made so secure that any leakage at all would be exceedingly unlikely. Complete assurance cannot be given that a tiny fraction of the radioactive material will not appear at the surface after a very long time; if such assurance is demanded, the whole nuclear energy enterprise may as well be abandoned. The maximum amount that might be released can be estimated with considerable confidence, and it would assuredly be minor in comparison with natural radiation. The setting of criteria must involve judgment about the amount of possible release that would be permissible and about the degree of confidence that can be placed in estimates of possible groundwater movement. From the standpoint of the author, the chance of escape of radionuclides in amount sufficient to harm future generations seems completely negligible.

A confirmed skeptic can always maintain, of course, that geologic predictions of future events are necessarily unsure, that unexpected climatic changes or rock movements might breach the most carefully designed bedrock cavern, that the nonleachability of solidified waste cannot be guaranteed for a million years, that future mining or drilling operations might by intent or by accident expose the stored waste, and that the long-term effects of radiation exposure are so little known that no addition to ambient radiation for this or future generations can be tolerated. An extremist on the other side can point out that escape of radionuclides from a properly constructed bedrock disposal site is extremely unlikely, that it can be made even more unlikely by providing paths for groundwater around the site and by adding materials that would be more effective adsorbents than ordinary rock, that bedrock sites would presumably be monitored so that corrective action could be taken at the first sign of difficulty, and that any remote chance of massive escape can be avoided by dispersing waste in many disposal sites rather than only a few. This argument has gone on for many years, and will doubtless continue for many more.

Basically the question is how much risk society is willing to assume to gain the benefits of a technological innovation, with the added complication that the benefits will be enjoyed by this generation while the risk is assumed by generations to follow, into a remote future. The setting of criteria involves weighing this risk in a context where some of the basic data for evaluating the risk are imperfectly known. How much radiation in addition to that already present on the earth's surface is acceptable, given that the ambient radiation varies widely in time and space, and that firm data on the long-term effects of low-level radiation are unavailable? How much assurance is needed for the integrity of geologic burial sites, and what estimated radionuclide release would be tolerable in case of remotely possible accidents, given that geologic knowledge does not permit firm extrapolation for times on the order of a million years? These are questions that must enter any assessment of risk and any attempt to set criteria for waste management.

They are difficult questions, and their answers can come only from a balance of many viewpoints. The author has suggested answers but they are necessarily those of a prejudiced scientist. Even among scientists there is wide diversity of opinion, so that science can provide no sure guidance. Scientists can describe the available data and point out their limitations as has been attempted in this paper, but decisions about criteria involve subjective aspects beyond the purview of science.

PUBLIC ETHICS AND RADIOACTIVE WASTES: CRITERIA FOR ENVIRONMENTAL CRITERIA

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An ethicist has recently remarked that whenever someone announces that the public needs to define and consider "the ethical and moral issues," the phrase usually "heralds the frustrated end of a discussion, or the beginning of a muddled argument" (Ref. 1). Judging from my experience to date, both as spectator and participant in radwaste discussions, the remark can be verified to a disquieting degree. I use the term "disquieting" not to impugn the competence or intentions of any person involved, but rather to call attention to a fundamental problem.

Many of those who invoke the phrase "ethical and moral issues" have a feeling that there is something worrisome about an action or social policy, but they also feel frustrated--unable to define precisely what it is, or why they feel it is bothersome, much less how to go about resolving it (Ref. 1).

INTERPRETATIONS

At least two interpretations of this state of affairs have a direct bearing on the subject of this Workshop. One interpreter, Hans Jonas, has made a compelling case that the root of this disquieting problem lies in the very concept of ethics, which many practitioners take for granted when attempting to define issues and devise criteria for their resolution (Ref. 2). This concept has assumed that the effective range of consequences of human action--hence human responsibility--is confined to the here and now, to known and intended effects, to defining "the human good" as a manifestation of the moral quality of "neighbor values"--justice, truth-telling, freedom, respect for individuals. Ethical codes for behavior in public and private life are a reflection of this value system. So conceived, ethics is anthropocentric, with the nonhuman world of nature serving as a backdrop, an ethically neutral instrument subject to human purposes.

But science, technology, and a population explosion have drastically changed the causal scale of human activities, as well as our integration within nature's complex, delicate web. As a consequence, traditional ethics has become increasingly problematic, because it is too individualistic, too shortsighted and piecemeal in its definition of issues, goals, and moral responsibility. When confronted with awesome changes in the range and power with which human actions have

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global effects continuing into future generations, a traditional "neighbor ethic" is inadequate to the task of defining criteria for effecting "the human good."

Instead of succumbing to frustration or paranoia, Prof. Jonas urges us to recognize that nothing less than a new concept of ethics commensurate with the new scope of human action is necessary. We must enlarge our perspective, not only with a more comprehensive time horizon, but also with a moral calculus shaped by a new set of imperatives. For example: "Act so that the effects of your action are compatible with the permanence of genuine human life;" or, "Do not compromise the conditions for an indefinite continuation of humanity..."; or again, "In your present choices include the future wholeness of human persons among the objects of your decisions" (Ref. 2). These imperatives imply, of course, a primary obligation: namely to acquire and disseminate an unprecedented degree and quality of accurate knowledge--both presently verifiable and predictive.

According to a second interpretation, the current problem about defining ethical issues should likewise be traced to an inadequate concept of ethics--but with an important difference. The difficulty is not simply that classical ethics is too individualistic and limited in its time horizon to identify and balance competing short- and long-term social values. Its principles are also too remote and theoretical, too generic, vacuous and indefinitely interpretable. Not only is a new genus of ethics required by changes in the scale of human action, but also a new subspecies--"public ethics" (Ref. 1). Conventional social ethics deals with issues about what constitutes the "good" or "right" ordering of human communities, and shaping long-term changes in social policies. By contrast, public ethics must meet a different set of exigencies:

1. It must deal with a precise problem about which a particular public decision must be made.
2. This matter of public concern is pressing; the problem must soon be resolved and implemented.
3. The decision to be made is, as a matter of prudential judgment, neither intended nor expected to force profound structural changes in the social order.

Current practitioners of public ethics have (with deceptive modesty) set forth three tasks for themselves:

1. They propose to confront vague, confused assertions about "moral and ethical issues" by exposing the hidden principles or reasons or conflicting values that lie at the root of a public concern, so as to transform them into an ethical argument that clarifies what can or cannot be justified.

2. Secondly, they endeavor to identify policy options, and then defend or criticize them by appealing to justifying reasons.
3. Finally, they propose to rank these policy alternatives in some order of ethically and morally preferable choices.

The practitioner of public ethics hastens to insist: the process of ranking policy alternatives necessarily involves assessing risks (personal and collective) over against benefits; weighing social and economic costs over against compensations; balancing a hypothetically fanciful, versus a verifiably predictable, erosion of the quality of life in the biosphere. Far from being merely crass utilitarian "trade-offs," these exercises in human judgment are the *sine qua non* of responsible ethical decision-making. They are antidotes to moralizing apprehensions. They tranquilize emotional prejudgments. Above all, they reflect the harsh necessity of enduring the uncertainty and risks entailed in making unprecedented policy decisions.

Since it is situated at the interface between ethics and politics, public ethics cannot indulge in the luxury of rarefied abstractions, indefinitely interpretable criteria, or vapid precepts. To the extent that politics is "the art of the possible," public ethics endeavors to practice "the art of discerning the morally preferable among the practical possibilities" (Ref. 1).

In order to be translated into actions and social arrangements, public ethics must meet three criteria. (1) Whenever values or principles are in conflict, the test of adequate and accurate knowledge of both risks and benefits must be met in an attempt to bring a balanced perspective to the conflict. (2) Secondly, since its purpose is to facilitate rather than postpone or impede action, an assessment of alternative policies must be based on practicable, demonstrable possibilities, not fictitious or fanciful scenarios. (3) Third, in ranking policy options, the criterion for moral preference among practicable possibilities must recognize our obligations to future generations, but not at the expense or to the neglect of a bias toward two priorities. One is that the obligations we owe to the living outweigh any claims of future generations, and our duty is to protect, not simply "mere survival," but also those conditions fundamental to human dignity and fulfillment. The second is that the fundamental needs of living persons are the justifying reason for preserving a sustainable environmental quality; those needs ought not to be sacrificed or subordinated to the pursuit of some ecological utopia (Ref. 3).

Having outlined this conceptual framework, I would like to underscore two reasons why interpretations about the problem of identifying "ethical issues" have a bearing on the discussion at hand.

In the first place, if indeed the confusion and disagreement about ethical issues raised by radioactive wastes ought to be traced to two different conceptions of how ethics should go about defining "the human good" (one of which centers upon individualistic, short-term, piecemeal considerations, whereas the other insists upon global, interdependent, long-range imperatives) clearly, that conflict cannot be debated or resolved in this setting. Its importance is certainly to be recognized and reckoned with--but as a factor limiting the satisfactoriness of my comments.

In the second place, if one is persuaded (as I am) that the task of developing environmental criteria for radioactive wastes is more proper to public ethics (because it is closer to the realm of action and practicable possibilities), then the ethical issues to be raised will reflect the particular exigencies of that methodology.

PUBLIC ETHICS AND THE PROBLEM OF RADWASTES

From the perspective of public ethics, therefore, I propose to turn to the first order of business, namely, how to formulate the problem of radwastes. An extensive review of the literature should convince anyone that there is little or no consensus about what the parameters are or how to delimit the problem. Since the formulation of any problem will predetermine the criteria for what counts as an acceptable solution, the primary ethical task is pivotal.

The origins, locations, and volume of radioactive wastes are matters of fact. It is also a matter of scientifically established fact that adverse health effects, somatic and genetic, may result from exposure to sources of ionizing radiation under conditions where the dose is in excess of certain levels. Mounting public concern over radioactive wastes (from the commercial nuclear fuel cycle, from military weapons manufacturing, from uranium and phosphate mining, and from hospitals and laboratory research facilities) is also a matter of fact. But it is a matter of value judgment that these wastes ought to be considered as a potential source of unacceptable, hazardous risks to the environment.

In the interest of definitional clarity, the term "wastes" deserves to be applied with a modicum of technical precision as well as respect for ordinary usage. The term denotes anything that is unproductive, or has exhausted its value, or is without immediate or foreseeable utility for fulfilling human needs. So understood, the term "wastes" is ambiguous at best when applied to spent reactor fuel that can be reprocessed so as to recover additional fuel resources. (To establish that spent fuel ought to be reprocessed requires ethical justification within another context.)

Further distinctions between high-level wastes, transuranic wastes, and low-level wastes have been made on the basis of two factors: the degree of concentrations of radionuclides, and the quantity of radioactivity present as expressed in the "half-life" (rate of decay) of certain actinides or isotopes.

Both in popular and scientific literature, it is increasingly fashionable to derive at least three lines of argument about the radwaste problem from this one factor: namely, the mind-boggling time scale measured by the half-lives of certain actinides and long-lived fission products. Using this single yardstick, radioactive wastes are perceived in the public arena to be an unprecedented, unique, man-made problem--"a matter of life and death," (according to the media) "a million-year risk," "a Faustian bargain" or "technical fix" made by energy junkies and bequeathed to defenseless future generations.

In the first instance, because invisible yet potentially adverse health effects are associated with them, the terms "radioactivity," "radiation," "toxicity," and "radiological impact" have been used (sometimes interchangeably) to argue that nuclear wastes emit levels of radiation, the environmental and public health impact of which constitute unique and unprecedented risks. As the inventory of radioactive wastes increases--both in volume and curies--a risk-benefit mode of analysis allegedly breaks down. The present generation reaps tangible benefits from nuclear power sources, but the risks attached to the radwastes are exported far into the future. The risks are not only associated with, but are measured in terms of, the long half-lives of radioactive elements. Unless and until the wastes are reduced to innocuous levels by natural radioactive decay processes, the risks to the environment and public health will perdure. This line of argument has issued in an ethical judgment that when a risk-benefit assessment is applied, the production of radwastes is a violation of distributive justice. Trade-offs between present benefits to living persons versus risks to future generations are ethically unjustifiable.

In a second instance, the yardstick of radioactive half-life pervades the legacy-longevity question. Are radwastes a "million-year problem" or a "thousand-year problem"? In either case, no knowledgeable person would ever rely on expectations about the stability and longevity of social institutions. Presumably it is an ethical imperative that our legacy to future generations be safeguarded. That is, we ought to define and standardize a "Radiological Impact Limitation Guide," defined as a "minimum acceptable upper level radiological impact limit" (Ref. 4). Its intent would be to minimize any "dose commitment" to a population from radiation sources, on the assumption that there would be some spewing forth from a repository, either as a result of accidental disruptions, or intentional intrusions. Moreover, the technology applied to radwastes should strive to reduce the "million-year problem" either in duration or volume--that is, by containment and geological isolation or by processes of partitioning, fractionation, and transmutation. Here again, the longevity of radioactive half-life dictates the problem and proposals for a solution. It would appear that our ethical responsibility to future generations is not sufficiently fulfilled by sequestering wastes indefinitely; we must also set regulatory standards that limit a potential radiological impact on populations from a hypothetical radiation release.

In a third instance, the literary imagery of Faust has become an appealing device for arguing that short-sighted technical fixes have unleashed a demonic power to destroy humanity. Once again, radioactivity as measured in thousands of years of half-life, infuses with enormous symbolic power the reprehensible consequences of our "Faustian bargain." In exchange for short-term materialistic benefits from more and better hardware, man has created a long-term radioactive monster against which our descendants must protect themselves for centuries.

Underlying these three versions of the problem about radwastes is a common denominator. The risk-assessment, the legacy-longevity problem, and the short-term versus long-term "Faustian bargain" are each predicated on one assumption: that the mere existence of a potential source of radiation constitutes, or is equivalent to, an unprecedented biohazard. Moreover, the perceived risks are identified in such terms that the measure of their magnitude is taken as equivalent to the million-year rate of decay associated with actinides and isotopes. Hence the risks and unprecedented biohazards exist in the environment "until the natural radioactive decay reduces the waste to innocuous levels."

FIRST ETHICAL ISSUE

The first ethical issue is this: should the formulation of the problem of radwastes be derived from this assumption? If unacceptable risks to environmental quality are measured in terms of the half-life or rate of decay of toxic elements, then we should immediately suspend the present program for this Workshop and instead concentrate on the problem of permanent geological disposal of arsenic and chlorine, the half-lives of which are infinite. They are not radioactive and will never decay to harmless levels. They have been and will continue to remain in the biosphere--not for a thousand or a million years--but forever.

Arsenic trioxide, a pesticide whose toxicity when ingested is 50 times greater than plutonium, is not sequestered in geologically stable regions. It is dispersed where food is grown. Note well: although this pesticide is not very commonly used, "more of it (in weight) is imported every year than all the nuclear wastes would amount to if all United States [electricity generation] were nuclear" (Ref. 5).

To balance our judgment in another way: the quantity of arsenic imported into the United States each year is enough to constitute one billion lethal doses (Ref. 6). If risk is quantified as equivalent to a potential for lethal "dose commitments" to a population, the hazards to our population of 213 million are of a frightening magnitude. Why is this biohazard not the subject of this conference? Because it is familiar, and there is no public concern over it. As a toxic substance, arsenic has for centuries been treated accordingly, and is strictly controlled in industry or wherever it is available in the marketplace.

Dr. Ralph Lapp has offered still another perspective from which to view the assumption in question (Ref. 6). Radium is present wherever natural uranium occurs in the earth's crust and may be carried off in surrounding water. According to studies at Argonne National Laboratory, persons exposed to such water at various locations in New England, Illinois, Iowa, etc., have exhibited what is called "a significant retention of radium." According to a 1976 Environmental Protection Agency (EPA) survey, some 500 United States community water systems "exceed a level of 5 millionths of a microcurie of radium-226 per liter." (Parenthetically, it should be noted that when ingested, earth-locked radium is 2,000 times more deadly than the same weight of plutonium-239.)

> In July 1976, EPA promulgated a ruling that all water systems serving United States communities will have to be monitored for radium, and those with more than 5 picocuries (i.e., a millionth of a microcurie) per liter will be required to remove the radium by chemical means.

According to EPA estimates, such radium removal will cost some $10 million. The reduction in radium exposure is expected to save almost four lives per year (Ref. 6).

Here we have not only an underlying assumption that a naturally occurring source of radiation in drinking water, measured in a millionth of a microcurie, constitutes an unacceptable biological hazard to public health; but the applied risk assessment reveals a startling inconsistency. If a Federal regulation requires certain communities to spend over $2 million to save one life from exposure to radiation risk, should not the EPA be consistent and compel the medical facilities in every American community to spend far greater sums of money to eliminate excessive exposure to diagnostic X-rays and radiopharmaceuticals? According to one estimate, medical X-rays exact a cancer toll of 2,700 deaths per year (Ref. 6).

Clearly, there is a serious conflict between the problem-formulation and risk-assessment of radiation hazards conducted by a Federal regulatory agency, and the risk assessment of an American taxpayer.

How shall public ethics endeavor to clarify and perhaps resolve this conflict in values? I have suggested that an ethical obligation to acquire more adequate knowledge might ensure a more balanced perspective.

It is instructive that our federal government has spent over $1 billion in the past three decades to research the biological effects of nuclear radiation. Is there not a fairly obvious correlation between the massive information flow to the public about radiation hazards, and the mounting public concern to which regulatory agencies want to appear responsive, protective, and indispensable? Judging from my professional experience, the public is more knowledgeable (at least, superficially) about the potential adverse health effects from radiation (or to be more accurate, the relationship between conditions of exposure, dosage, and related effect) than about many highly toxic chemical agents in common industrial use. Should it not also be a potential public concern that drinking water supplies contain chemical and biochemical poisons? The undetected yet cumulative health effects of these poisons could prove more damaging than a few picocuries of radium. Should not taxpayers' money be spent on more extensive research into these toxic chemicals?

Such research might turn up alarming data. Scientists have so increasingly refined their instrumentation that, whereas chemical concentrations once were detected in terms of parts per thousand, it is now possible to detect parts per billion, and even parts per trillion of a chemical in our food or water. Are such numerical measurements any automatic index of the magnitude of a risk to health and the environment? Certainly not to a technical expert; but they can and have been used to bemuse the so-called "plain man" for ulterior purposes.

Among others, William Lowrance urges us not to succumb to historical amnesia. When many environmentalists deplore the degradation that technology and its energy applications have (in their eyes) wrought on this planet, he suggests that we remember what life at the turn of the century was really like--spoiled food, impure water, boiling laundry kettles, the backyard lye pot; nutritional deficiencies and poisoning from many natural/organic vegetables. Rivers were so filthy with raw sewage and wastes, that according to the saying of the time, "Bait died on the hook!" The major pesticide, sprayed indiscriminately on anything from apples and grapes to potatoes and strawberries, was lead arsenate or "Paris green." Red food coloring was produced by lead chromate--a horror to today's biochemist. Have the hazards increased in fact, or only in our levels of perception? Lowrance puts the case well:

> We now have the luxury to worry about subtle hazards which at one time, even if detected, would have been given only low priority beside the much greater hazards of the day (Ref. 7).

More refined and extrapolated technical data about biohazards are clearly not sufficient. Risks are in the eye of the beholder. Clarity at the level of perception is an ethical imperative.

Let me recapitulate my argument. Contrary to public perception of the unique, unprecedented biohazards introduced into the environment by radwastes, neither mere presence, nor million-year rates of decay, nor numerical calculations of the lethal doses contained in a substance based on half-lives or parts per million should be used as an ethical basis for formulating a problem about any biohazard, especially radioactive wastes. Moreover, to protect the ethical canons of informed consent, no adequate risk-assessment can or should be made exclusively by a regulatory agency subsidized by taxpayers and/or consumers. It is an ethical anomaly, to say the very least, that the agency mandated to protect our environment has not been required to submit for public review any socioeconomic impact statement justifying its targets for regulation, and the expenditure of public monies.

In the interest of a more balanced perception, I offer three contentions about formulating the ethical problem of radwastes.

First, the degree of risk from any alleged biohazard must be measured as the coefficient of clearly defined conditions under which exposure can be calculated. The risk exists in relation to concrete individuals, not hypothetical populations. The index of risk is not "mere presence" in any environment for however many years, but likelihood of exposure.

Second, the risk cannot be said to exist unless or until a potential biohazard is able to penetrate and enter into, travel along, remain unobstructed and undiluted by environmental pathways to life. The reference case to be used in predicting these pathways should be naturally occurring, familiar pathways for toxic substances--including natural radiation sources--which human beings have lived with in their environment throughout history. Those who insist upon imaginative scenarios about descendants who are technologically primitive yet able to dig a thousand meters underground into geologically interesting terrains should also be required to compose imaginative scenarios about future dispersals of arsenic and chlorine in a food chain or water supply, or about carbon-dioxide poisoning of the atmosphere if we are forced to burn coal at projected rates for 400 to 500 years. Such scenarios would restore balance to any risk-assessment.

Third, any potential adverse health effects must be defined in relation to a significant dose received by individuals. Those who might presume to have the competence to determine for future populations their so-called "dose commitment" or its numerical limits certainly project an aureola of responsible concern. The idea is philosophically attractive. But returning to the real world, how does a regulatory agency expect to arrive at a number? To be significant to the public, would it not have to be exaggerated? Considering the variations in natural background radiation in different geographic regions and altitudes on this planet, the different medical expectations and practices of urban or rural communities, and the impossibility of enforcement--what possible social good is to be served by expending public money on this kind of health protection? If any standard can be set, it should be an Ambient Radiation Standard for specific, occupational fields that exist where individual persons go who can be monitored for any noteworthy health effects. If a dose in relation to ambience is high, it is measurable; if it is low, it is lost in the background. Moreoever, "future populations" do not make intentional intrusions into an underground repository; individuals do. They would be exposed to the source of radiation, not populations.

On the basis of these contentions, I suggest that the problem of radioactive wastes is neither unique and unprecendented, nor has it been properly formulated from an ethical perspective. We have always lived with toxic elements in our environment, and they have not been sequestered with the skill, forethought, and planning applied to radwastes. From an ethical perspective, public concern has not only been inflated for political purposes, but it has been aimed in the wrong direction. To exercise ethical responsibility, the public should focus its concern on a proliferation of regulatory agencies whose flawless bureaucratic logic has paralyzed the process of decision-making. That paralysis has prevented anyone from implementing one of several feasible disposal options for which the technology already exists in fact, if not in execution.

Furthermore, because the present volume is small and the evolution of improved technologies is to be expected, some visionaries insist on a prior demonstration now of what will be perfected 50 years from now. Instead of tailoring the method to the present volume, paralysis reigns.

From the perspective of public ethics, the morally preferable among present practicable options should be the one that will--in the technical judgment of those competent to make it--provide maximum, multiple barriers between radioactive materials and such pathways to life as can now be foreseen.

CRITERIA FOR ENVIRONMENTAL PROTECTION

In my judgment, four criteria for protecting our total social and physical environment against harm from wastes have already been met:

1. The technology for deep mining in salt or rock is well known and in use.
2. Geologically stable regions can, with as much certainty as accepted in other long-term decisions, replace our reliance on the stability of any future social institutions.
3. Demonstrable methods of solidification, transportation, and disposal can occur without any more threat to environmental degradation than exists from the handling and transport of much more toxic substances in common use.
4. If not obstructed by interminable costly delays in the process of implementing an option, the economic cost is only a small percentage of the total amount already invested.

But it is a fact of life that all criteria are not created equal. Some are created to facilitate action. Others are created to paralyze it by being infinitely interpretable. Some are created by lawyers and professional interveners who (for their own purposes) want them to be amenable to the constraints of a formalized legal structure and an interminable process of adjudication. Others are created by ordinary citizens who must worry about social and economic hazards to their environment, having little to do with esoteric and comparatively insignificant quantities of contaminants which they will rarely encounter--but which are attractive objects of research and regulation for those who are in a position to make a case for massive funding.

SECOND ETHICAL ISSUE

And so we are confronted with a second, major ethical issue. How is the public decision-making process to be made more ethically responsible in serving the common social good--that is, a more just and balanced protection of public health and safety? How can a corrective be applied to a paralyzing social mechanism? Persons with far greater wisdom than any I possess are convinced, from the record of the last hundred years, that regulatory agencies are inherently deficient. Problems are segmented, proliferated, and the current of accountability gets passed along only one way: downstream. Costs are externalized and passed on to angry taxpayers. Enforcement of regulations has to be turned over to the judicial system with interminable, irreversible delays. The best intentions in the world eventually come to grief in a creeping Parkinsonianism. Frustrations within the system are mobilized into empire-building.

What instrument will cut the Gordian Knot that ties regulatory proliferation to unending conflicts of interest vested in government agencies and professional interveners? Surely one does not waste time untying the knot. One severs it once and for all. But how? By proposing and insisting upon morally preferable options.

Any preferable option would have to reckon with a central question. Why has the concept of regulatory agencies been accepted for so long, despite its glaring intrinsic deficiencies? The major reason seems to be that the public has labored under a profound misconception--never more apparent than in the debate over the disputed "safety" of nuclear reactors and of radwaste disposal options. The "plain man" thinks (or is led to believe) that "safety" is an intrinsic, unconditional, measurable property that some system or product can and should possess. Consequently the regulator is appointed and paid to measure approximations to that intrinsic property. It is the business of the watchdog regulator to make more stringent regulations, presumably to come ever closer to that property by "reducing risks." But the only risks he is expected to monitor and minimize are a small percentage of the total risks tolerated by members of the public. His job is not to be reasonable or to worry about the social and economic impacts of his ever-changing regulations. Just what value judgment does a regulator use when he demands more and more costly levels of safety? Is he only giving the public what it wants? Not at all. To paraphrase Tobias Burnett (Ref. 8), a regulator can no more admit that what he regulates is "safe" than any other professional can admit that his job is finished and he has become unnecessary. No matter how minor a risk is, it can always be reduced. There is no number that cannot be divided by 10.

The public has yet to realize, apparently, that safety is not an intrinsic property, measured by approaching zero risks. It is a relativistic, subjective, evolving, shifting judgment based on one's values. It can never divest itself of risks. It can only judge their acceptability. There are as many judgments of "safety" as there are people and value systems. Furthermore, the public has not yet been forced to wrestle with the ultimate question: just how much safety are we willing and able to pay for? Zero risk and absolute safety are costly illusions.

If a system of proliferating regulations is bankrupt and needs to be replaced, a morally preferable option would have to restore a balance between the public's misconceptions about safety, and its willingness to pay the social and economic costs.

There is another possible explanation for our tolerance of the regulatory agency-system. That mechanism is a reflection of our basic commitment to legalistic, individualistic values.

Based on the belief that we are special, and that more of anything is better, Americans have inflicted upon themselves what Jerold Auerbach calls "a plague of lawyers (Ref. 9). Unlike the divinely imposed Biblical plagues, this one is the incarnation of our basic American values: "our consuming individualism, unrelenting contentiousness, and discordant heterogeneity." Seen in our public mirror, we are "one divided nation, under lawyers, with liberty and justice for some" (Ref. 9).

Despite a sustained crisis of legal authority in recent years, our response has been, quite characteristically, to make new laws and regulations, and breed more lawyers. The unresolved tension between legalistic formalism and substantive justice is acute, says Professor Auerbach, but it is likely to remain.

> The plague may be our terminal illness, but Americans probably prefer the disease to any cure that would purge us of our individualistic, materialistic, competitive traits....Modern America could not easily survive the absence of lawyers. They not only sustain and profit from its rapacious individualism; simultaneously, they commit the society to legalistic values, which offer the only thin veneer of unity that Americans can tolerate (Ref. 9).

On this view, if a system of regulatory agencies is to be replaced by a morally preferable option, it would have to leave intact a legal system available to individuals for settling conflicts between competing value systems and relativistic judgments of safety.

The fact remains that there is an urgent need for a social mechanism that can be independent, and do its work of auditing and enforcing standards that will protect our total social environment with as few conflicts of interest as possible. One of our most pressing social issues is the so-called "crisis of public confidence" in professional experts. The more arcane and complex a scientific or technological development becomes, the more constrained is the "plain man" to fortify himself against erosions of his own level of understanding and his familiar world. Unable to stop the world and get off, he has little recourse except to turn to the government and its regulators to stop the whole process.

The crisis is not generated by professional incompetence of experts, but by the social mechanism for enforcing rules and regulations through which that expert testimony is forced to pass. Perhaps a Science Court could serve, in certain cases, to process an increasingly sophisticated technical knowledge, and then determine what the "scientific truth" is. But the setting of standards, and the certifying that they have been met, will have to be carried out by an entirely new social mechanism.

I will not repeat here the persuasive arguments for the creation of a new profession--one that replaces government regulatory agencies--namely, the certified public professional. Like his financial counterpart, the certified public accountant, the certified professional (in whatever profession) would be mandated to audit and submit to public review the work of scientists, engineers, and technicians as they function in education, industry, and business. Certified public professionals would have their own standard-setting and regulatory peer review. Their professional judgment would establish standards for safeguarding public health and our total social environment from encroachments of technology.

Instead of an external regulation and externalized costs borne by taxpayers, this would be an internal mechanism. It would internalize the costs of regulating industry and business, just as occurs with financial audits. It would internalize accountability. The threat of litigation from investors, shareholders, or others--upon disclosure of failure to meet professionally-established standards for safe-guarding public health and the environment--would regulate any profit-making corporation with far greater effectiveness than an external government agency.

Is there any hope that this morally preferable option for protecting our total environment can be implemented? Yes. The public is being persuaded, although in qualified terms, that there are limits to growth. It is a question of time, but eventually Americans will realize that there are limits to growth of undue process. Slowly but surely, we are beginning to understand the impact on our total social environment, in both economic and social deprivations, of regulatory overkill and legalistic power plays.

The public concern over radioactive wastes is primarily perceived as a concern for public health and safety. But is it not more fundamentally a symbol of the never-ending conflict between individualism and civilization? Americans may never surrender their basic commitment to legalistic, individualistic values. At the same time, we are bound to be persuaded by the language of massive social deprivations that "the limits to growth of undue process" have already been overreached. The burden of resonsibility for having inflicted unnecessary and unjust social deprivations by costly delays will not be easy for us to carry.

Whatever else may be said in this or any other public discussion, the final word on radioactive wastes properly belongs to Madame Curie: "Nothing in life is to be feared. It is to be understood."

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APPROACHES TO RADIOACTIVE WASTE MANAGEMENT CRITERIA DEVELOPMENT:
SUMMARY AND CONCLUSIONS OF WORKING GROUP 1

APPROACHES TO RADIOACTIVE WASTE MANAGEMENT CRITERIA DEVELOPMENT

Working Group 1 reached a general conclusion that, although desirable, environmental protection criteria may be extremely difficult to establish, especially in a form that would be effective for all types of waste. It was also generally agreed that although sufficient data may exist to set numerical criteria, they have not been brought together as yet. Despite these limitations, environmental protection criteria should be achievable, protect the general population that may be at risk, mitigate against unacceptable exposure of individuals for several generations, be measurable, be economically feasible, recognize both the operational and disposal phases of waste management, protect this and future generations, be flexible (that is, leave room for improvements such as new technology), and provide more assurance of environmental protection from most wastes than now exists.

DEFINITIONS

To clarify the meaning of any developed criteria and the materials to which they apply, certain terms will need to be defined. One of the first such terms is "radioactive wastes." It was agreed that EPA should not develop or define specific and detailed categories of radioactive waste. The following broad definition of radioactive waste (offered in full recognition of the existence of more detailed definitions) is proposed for the purpose of environmental protection criteria: radioactive waste is all that radioactive material with respect to which a decision has been made by the cognizant authority to place the same in permanent storage or a permanent mode of disposal at discrete sites designated for those purposes, and shall exclude radioactive material for which a determination to withhold has been made. Also excluded are radioactive releases from facilities involved in production or reprocessing of nuclear fuel and the generation of electricity from nuclear fuel, which are subject to federal and state licensing and regulation. (Note: This definition does not preclude the possibility that materials designated as "waste" may or may not have value now or in the future.)

BASIS, FORM, AND METHODOLOGY FOR CRITERIA

In addition to the broad requirements for environmental protection criteria for wastes noted above, more detailed bases may also need to be examined. The working session generally agreed that the basic philosophy should espouse containment and/or isolation; basing such a philosophy on

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"decay to innocuous levels" was rejected because the meaning of such a phrase is too imprecise for any practicable use. Regardless of the type of the radioactive waste, the criteria should be applicable to any exposure of people, that is, they should be generic for mitigating risks due to radiation exposure. A number of participants expressed the view that the criteria should result in umbrella-type numerical standards for anticipated exposure of individuals and population groups, and that within these umbrella-type requirements criteria should also require the application of cost-effectiveness considerations to reduce risks for specific sites, methods, or wastes. The desirability of a zero release, zero dose requirement was discussed. Three views were apparent. First, although it may be desirable goal, it presents great problems from the standpoint of engineering and criteria. A second viewpoint was that some members of the public will expect a principle of zero release and zero dose from the management of radioactive waste. A third view expressed was that some members of the public expect some release and dose as a tradeoff for the benefits attained.

In order to facilitate cost-effective evaluations, criteria should contain a requirement that an assessment be made using established methodologies of anticipated risks to both individuals and populations. The criteria should not provide guidance on these methodologies. The concepts of acceptable or unacceptable risks, and criteria for risk reduction in a cost-effective manner, should be employed uniformly for all categories and sources of radioactive wastes. It was recognized, however, that any subsequent protection standards, expressed in numerical terms of any kind, may need to be different for the various categories and sources of radioactive wastes.

Within these overall considerations it was agreed that at least a certain minimum level of public health protection should be assured and that this assurance is more important than cost. Waste disposal was believed to be capable of being conducted within any requirements that assure public health protection in the broad meaning of the term.

Risks due to accidental circumstances were thought to be outside EPA's purview to state criteria for radioactive waste disposal. It was recognized that risk needs to be addressed by those responsible for regulating site-specific applications in the interests of environmental protection. Because of this interest, general environmental protection criteria should include the articulation of a philosophical approach which reflects:

1. An obligation under generally accepted radiation practices to keep exposure levels as low as are reasonably achievable below such reference limits as may be identified.

2. An obligation to assess the potential accidental events which might occur.

LONG-TERM CONSIDERATIONS IN CRITERIA

The extent to which the need for long-term care must be considered in establishing environmental protection criteria for radioactive waste disposal was discussed, and the following concepts were agreed upon:

1. This generation has a responsibility to future generations to ensure that they will not be deprived of the possibility of reasonable progress. It was agreed, however, that we cannot presume to protect all future populations against their own actions and all contingencies. The risk assessment of any radioactive waste disposal method or facility should consider the consequences of potential intrusion, either deliberately or accidentally, by an individual or a population group.
2. The criteria should not require a consideration of or make any assumptions about the form or stability of future social institutions. The criteria should require identification of positive as well as negative legacies related to radioactive wastes and their origins.
3. The criteria should address the risks and disposal standards associated with radioactive wastes in the broad context of the comparable risks and disposal considerations for all biologically hazardous wastes. Any criteria developed should be commensurate with the hazards. (The members of the working session suggested specifically that a high degree of coordination within EPA is important, for example, between the Office of Radiation Programs, the Office of Solid Wastes, and other appropriate groups.)
4. The criteria should be based on assessments or projections of possibilities of real risk (e.g., health effects) to real individuals and/or populations. In addition to direct effects on humans (e.g., health effects), the criteria must consider possible effects on the utilization of natural resources in the future.

PHYSICAL AND OPERATIONAL CONSIDERATIONS FOR CRITERIA

In considering the relative importance of environmental barriers such as geologic formations, as opposed to engineering controls (e.g., matrices, containers), the consensus was that the barrier provided by a geologic formation is more important when considering long-term care for all types of wastes. There are, however, situations where engineered controls are necessary. For example, it is essential that high-level and transuranic wastes be contained (e.g., either by matrix and/or container) during the validation phase or retrievable time period of the repository (e.g., 50 years). In addition, there are numerous specific criteria which can be imposed on classes of wastes or disposal sites. For example, non-transuranic low-level wastes should be placed in media that are unfractured, have low permeability and are amenable to study. The medium should also be large enough so that concentrations of radioactivity in surface and ground waters at the boundary will be within established standards. For shallow land disposal of low-level wastes engineering controls are also necessary to keep water from penetrating to the waste. It is believed that geologic disposal is not too expensive; however, other methods which may prove practical must continually be examined and reviewed. It was concluded that high level waste should be retrievable until it can be demonstrated that the isolation is secure. This time period cannot be defined at this writing. However, it is assumed that the institutional controls established in the future will be responsible for complying with this criterion. Low-level waste disposal facilities need not be constructed on a retrievable basis. It was felt that the question of costs could not be addressed at this time.

There is definitely a need for preplanned emergency response procedures for credible accidents. There is also a need for monitoring both during the operational lifetime of a facility and until safe isolation can be demonstrated. The time period for monitoring after facility closure was not ascertained. However, it was felt that for low-level waste burial sites, monitoring should continue until the migration rate has been determined. If effluent is found to exceed established protection standards, remedial measures should be available to protect groundwater. Also any monitoring after the closing of a facility should be done without violating the integrity of the facility. In addition, it should be demonstrated that any effluent reaching the biosphere will be at or below drinking water standards. This should be ascertained by competent scientists and engineers.

WORKING GROUP 1 EXECUTIVE COMMITTEE

APPROACHES TO RADIOACTIVE WASTE MANAGEMENT CRITERIA DEVELOPMENT

NAME	AFFILIATION
James E. Martin*	Environmental Protection Agency
Stanley Lichtman†	unaffiliated
Edward Struxness	Oak Ridge National Laboratory
William Holcomb†	Environmental Protection Agency
McDonald E. Wrenn	New York University
Judith Johnsrud†	Environmental Coalition on Nuclear Power
Keith J. Schiager†	University of Pittsburgh

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* Moderator.

† Panelists for Plenary Workshop Session, 5 February, 1977.

RESPONSE OF WORKSHOP PARTICIPANTS TO SUMMARY AND CONCLUSIONS OF WORKING GROUP 1

Second Plenary Workshop Session

JAMES E. MARTIN (Environmental Protection Agency, Washington, D.C.): My name is James Martin and I am chairman of this Workshop and moderator of Working Group I. The other panelists in this group are William Holcomb, from The Environmental Protection Agency in Washington, D.C.; Judith Johnsrud, from the Environmental Coalition on Nuclear Power, State College, Pennsylvania; Keith Schiager, from the University of Pittsburgh, Pittsburgh, Pennsylvania; and Stanley Lichtman, from Ann Arbor, Michigan. The first question is from William Lochstet.

WILLIAM A. LOCHSTET (Environmental Coalition on Nuclear Power): The definition of waste presented gives some "cognizant authority" the ability to define it later. It would be better to use concrete examples including those currently in existence and those expected. Group 2 considered "waste" to be what is generally called high-level waste from the fuel reprocessing operation. I think I found the whole definition unmeaningful. We felt we knew what high-level waste was and we clearly understood it and we did not bother to pussyfoot around about trying to say what it might be. We have high-level waste and we have to deal with it. To legislate it out of existence does not solve the problem. This is what I am trying to say.

JAMES E. MARTIN: I might comment that as I reflect on the layout of Working Group I it was broader, or at least it had a broad subject to try to address areas where criteria may be needed. I think I recognize that there is probably going to be quite a bit of redundancy between these reports; but that is just the natural consequence, I guess, of dividing into threes because there is going to be presentation of some kind of information but certainly from different views. How we are going to sort that out I do not know, but we will just have to make an attempt to do so. We were not trying to preempt the other groups, either defining or commenting, but to state what the consensus of that group was. Dr. Schiager, did you want to comment?

KEITH SCHIAGER: I think the thing we were brought back to a number of times in our Working Group was the fact that we are not dealing only with high-level waste. The entire spectrum of radioactiave waste was to be the subject of the Workshop and therefore we were looking for a definition that covered that entire range. This is why we worked on a definition even though there are plenty of definitions in existence for various categories.

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STANLEY LICHTMAN: It seems unclear to many people what waste is. Some people would be very offended if you disposed of what you call high-level waste. They would want to remove things from it first. So we feel that waste becomes waste when a decision is made to get rid of it regardless of its value. There was a great deal of dicussion on that point.

LOCHSTET: I think that that is inherent in deciding what quantity of material this meeting is all about. I do not have any quarrel with the high-level/low-level problem, and I think we all would agree with you, at least from my point of view. This whole question of whether it is desirable or somebody is going to want it later begs the question of what the problem is we are talking about here.

MARTIN: Mr. Lawrence Jones.

MR. LAWRENCE JONES (Pacific Legal Foundation, Washington, D.C.): Thank you, Dr. Martin. I would like to have that added comment regarding zero release repeated. I have some strong feelings about concepts of zero emission.

SCHAIGER: Zero dose requirement was discussed with two views apparent. First, although it may be desirable to attempt to achieve, it gives great problems from the standpoint of engineering and criteria. A second viewpoint was that some members of the public will expect a principle of zero release and zero dose from the management of radioactive wastes.

JONES: I would like the record to reflect that it is my conviction that some members of the public would expect a third outcome. I believe that there is a significant segment of reasonably well-informed public who recognize that it is mandatory to accept some release as a trade-off for the benefits coming from nuclear energy. I do not think the record would be complete without reflecting that fact. I do not purport to speak for the entire public but I do speak for some of it. I believe that it is an insult to the nuclear technologist's intelligence to expect him to design a system that will result in zero emissions. If this is even going to be considered then we must abandon nuclear technology in total, and that to my way of thinking is unreasonable. I believe that if the public is given the facts surrounding the effects of ionizing and radiation they will make an intelligent and reach a reasonable conclusion on the question.

MARTIN: I will be sure that the record reflects your view. Next speaker is Mr. Peter Littlefield.

MR. PETER S. LITTLEFIELD (Yankee Atomic Electric Co., Westboro, Mass.): Comment on Working Group I Summary and Conclusions, page 1-40, second paragraph, first sentence. This sentence does not express the consensus of the working group as I understood it. The group stated that some level of public safety should be assured regardless of cost. Beyond that level further reduction of dose, etc. must be on a cost-effective basis. That was an attempt to be a clarification of what I understood we agreed upon in the working group; that is, there was some minimum level of safety that should be assured, but beyond that, any further reductions should be on a cost-effective basis.

MARTIN: Is there any disagreement with that consensus?

PANELIST: I think that is a fair representation.

MARTIN: We will reflect that as such. The next comment is from Dr. Kim.

DR. KYO S. KIM (United Engineers & Constructors, Inc., Philadelphia, Pa.): I was in Working Group 1 and I do not remember defining a waste in such a manner as page number 1-39 says, excluding the waste involved in the production of reprocessing nuclear fuel or generating electricity. Well, granting this to be the definition that Working Group 1 has made up--which I do not quite believe is so--in other places in the Summary it consistently and repeatedly says that the criteria should be umbrella-type generic, applicable to all waste. I think this contradicts itself and also 40 CFR part 190. This is just one of my thoughts that is not quite clear.

LICHTMAN: May I comment?

MARTIN: Yes. Dr. Lichtman will comment. Maybe he can clear it somewhat.

LICHTMAN: The reason for excluding for present purposes, for the purposes of this meeting and the EPA's present task--excluding releases from production facilities and power generating facilities--these are releases. Effluents and releases of that type are first of all not contemplated to be subject to the kind of storage that we are discussing here; and secondly, they are covered by other standards and regulation. So we excluded them from the definition we are discussing here.

KIM: But we are now making criteria for radioactive wastes regardless of origin or where it is produced. The whole sentence sounds like it is umbrella-type generic and applicable to all waste, so whatever criteria we are setting here will be interpreted in the future as applicable to all waste.

LICHTMAN: I hope not and one should try to avoid that. The waste we are considering here excludes waste that is released in effluents by these other facilities.

MARTIN: Mr. Chauncey Kepford.

CHAUNCEY KEPFORD (Environmental Coalition on Nuclear Power, State College, Pa.): In the long-term criteria on page 1-41, criterion 2 (as a criterion) should not require a consideration or make any assumptions of the former stability of future social institutions. That is fine. I am in Working Group 3 and we concluded essentially the same thing. Yet on the next page it says it was concluded that high-level waste should be retrievable until it can be demonstrated that the isolation is secured. Does this not impose quite a burden on future societies and generations? And how long are they going to have to stick around to insure that these wastes are indeed secure?

SCHAIGER: Well, I might comment on that, at least to what the intent of the working session was as I understood it. When we were talking about not placing any reliance on future institutions we are talking in generations beyond our own. When we were talking about monitoring, assuring the containment situation we were really speaking in terms of what is done in the generation that produced the waste. That was the intent I believe, of the working session, whether or not it is stated very well.

KEPFORD: Then, my criticism still stands because as I understand it our first repository will not be sealed until after the year 2000, which is essentially beyond this generation. Is that not right?

SCHAIGER: I do not know what is going to happen to the first repository. People have said what they are going to do. That discussion did come up in the Working Group, though, and what I am saying, is the response was that we were here to put down some criteria that we thought were proper regardless of what someone may or may not have planned.

MARTIN: I will move on to the next question; I have to wrap this up. I will give you one more minute to get a card up here, and I have to close it off here so we can move on to the next report. The next comment is from Mr. R.L. Shoup.

R. L. SHOUP (Union Carbide Corp./Nuclear Div., Oak Ridge, Tenn.): I had a comment or a question on page 1-5. You made the statement that high-level waste should be retrievable until it can be demonstrated that isolation is secure. I would like a little clarification as to how can retrievability and demonstrated isolation be achieved simultaneously. They seem to be incompatible concepts.

MARTIN: Mr. William Holcomb.

WILLIAM HOLCOMB: As I understood from the group and also from the Energy Research and Development Administration

(ERDA), they are going to establish or operate a repository probably on what they call a validation phase for a number of years to make sure that everything they thought about and designed is going to work properly. We are, of course, under the impression that, (and I think ERDA is going along the same line) they want to have everything that they put in the repository contained in such a way that they can remove it if they find that, perhaps that repository, that location, or their operational methods are not acceptable to their findings over a number of years. Now ERDA has not yet totally defined how many years they are going to , what you might say, experiment with this repository until they gather enough data to determine if it is an acceptable place to store. Once they do that they intend probably to go on and fill up the facility and when it is full then they will close it down. Therefore, I think the viewpoint of our group was, okay, as long as they are in this validation phase, we hardly recommend that they do maintain retrievablility because if something happens--something unpredictable that they did not consider--they still have the option of pulling it out and going to another repository. In addition ERDA is considering looking at more than one geological media or formation. Perhaps somewhere along the line they may find another formation that they feel is much better than their first one. I cannot speak for ERDA but that is a possibility.

MARTIN: Does that clarification satisfy you? Okay. The next speaker is W. H. Millerd.

W. H. MILLERD (Center for Science in the Public Interest, Washington, D.C): My questions reflect on page 1-41 number 4, which is a criterion that clearly reflects Dr. Maxey's evaluation of the situation. Although that is a very good philosophical question, it has a lot of practical implications; namely, it could be a request by the nuclear industry to be allowed to do as poor a job as the worst of our industries has done in the past, or it could be a support for the EPA's efforts to do a very good job on cleaning up the other wastes, in which case it could also be a request for a delay in handling their wastes until everybody cleans up their own house. As I suggest, making that the base of our criterion is extremely ambiguous and I would like some clarification, if there is any, from the panel.

Panelist: I think the feeling there was that we used the word that these risks should be addressed in the context of other comparable risks and so on. There is nothing in that paragraph that implies a delay, there is nothing there that says we should not follow the rest of the criteria which we feel are directed toward good radioactive waste disposal practices; but we do feel it is important that basic philosophies within EPA on waste management should not run countercurrent.

MARTIN: Thank you. The next comment is from Mr. H. Bryant Brooks, Tennessee Valley Authority.

H. BRYANT BROOKS (Chattanooga, Tenn.): On page 1-39 it is stated that environmental protection criteria do not exist. I submit that such criteria have existed for years, based on large data bases, and waste standards must simply be fitted in the existing framework.

MARTIN: Anyone want to respond or comment?
I will go to the next one. Dr. Frederick Forscher.

FREDERICK FORSCHER (Energy consultant, Pittsburgh, Pa.): You can read my comment.

MARTIN: Comment. What is meant by permanent storage or mode of disposal, that is, why call innocuous levels imprecise?

FORSCHER: It is aimed at the question of definition. There was a comment made in the paper on innocuous levels, and it is not precise enough. But before there were statements like, "We have to go to permanent disposals and permanent repositories." What do we mean by permanent? If we must define, let us define them all. The conclusion one reaches from this type of reasoning is that you cannot get away with imprecise words, either innocuous, or permanent, or secure, or as low as practical or economically feasible. You have to get to numbers, and numbers can never be zero.

MARTIN: I think you made yourself fairly clear on that.
Mr. Loring Mills, do you want to state your point or shall I?

LORING MILLS (Edison Electric Institute, Washington, D.C.): I was looking for clarification on two statements on page 1-42, the first one being on line 11 and 12 of the first paragraph. That paragraph appears to address both high- and low-level waste, and it also says, "it is believed that geologic disposal is not too expensive." I am curious as to what was really meant there in "geologic disposal," because in some people's minds the saltbed or the rock formation is the geologic disposal and it might not be a geologic disposal if it is the shallow land burial area. I was just looking for a clarification on that.

HOLCOMB: We define geological formation as anything in the earth's crust, be it shallow land, deep mines, deep excavation, or whatever. So if you are going to put it in the shallow land that is also a geological formation, that is a that is a burial.

MILLS: Okay, that clarified it. The second clarification was in the next to the last sentence on the bottom of the page. "In addition it should be demonstrated that any effluent reaching the biosphere will be at or below drinking water standard." I suggest that there might be some areas in the country where there are effluents adjacent to these repositories that would not meet drinking water standards from a natural standpoint. Thus, are you suggesting that the repository should purify those waters?

MARTIN: Thank you for the comment, and for pointing out the pitfall. Mr. Owen Davis, do you want to quickly state both of your.....

OWEN DAVIS (PG&E, San Francisco, California): The first one was for clarification on page 1-41 item 1, we have the statement that "It was agreed, however, that we cannot presume to protect all future populations against their own actions in all contingencies." Yet in item 4, the second sentence says, "The risk assessment of any radioactive waste disposal method or facility should consider the consequences of potential intrusion either deliberately or accidentally by an individual or a population group." Those two statements did not seem to jive.

SCHAIGER: There are probably a lot of things in here that do not really hang together, but the point of this was that you cannot necessarily guarantee protection but you can ask yourself "What if someone does get into a repository, how serious would the consequences be?" You can analyze it and at that point in the risk assessment phase of waste management you can in fact make a further decision of additional protective measures.

DAVIS: I think that sentence, then, should be tied to item 1, as a follow-on part of it. It would be logical to put it there. My second comment was on top of page 1-42 where we are giving examples of the waste form by saying it should be in a matrix or a container during the validation period or, further down, that non-transuranic low-level waste should be placed in a media that are unfractured low permability and amenable to study. I think these are site-specific criteria and represent a judgement on what would be required and not a part of criteria that, as I understand it, EPA is supposed to be setting.

MARTIN: Mr. Robert B. Shainker

ROBERT B. SCHAINKER (Systems Control, Inc., Palo Alto, California): Some of my points were covered earlier but basically the definition of nuclear waste as defined here seemed to be a moving target depending upon legislative decisions and I did not even get a definition of what decisions had occurred in the past in this sense to really get a handle on what it means today. I was really left in an uneasy state of mind in terms of what your definition of radioactive waste was. One clear point--is a spent plant, as an example, radioactive waste?--came up in Workshop 3 and we felt it was.

The second point is the third paragraph on page 1-40 starting with "Risks due to accidental circumstances were thought to be out of EPA's purview to state requirements for criteria for radioactive waste." I just do not understand that sentence. Could someone clarify that for me?

JUDITH JOHNSRUD: ....the uses of the terms criteria and standards, which seem to give us trouble all the way through the Workshop, are involved here but perhaps if the word, "standard" is used instead of "criteria" in that statement, it might help a little.

SCHAINKER: I think definitely the words, "criteria" and "standard" could be defined and I think it has been in EPA literature, but the general public should understand what the working definitions are. I am really concerned about the accidental circumstances. What was the meaning of that? Stating that something--whatever the accidental circumstance be--is outside EPA's purview just sort of strikes a cop-out chord on my part.

MARTIN: That is not necessarily EPA's view. That was the view of the people in the working session. We have not heard from the other two working sessions. I personally think the statement is rather clear; it was a conclusion that EPA should not in development of criteria address accidental circumstances; it was outside of its purview.

SCHAINKER: I just do not understand that. Give me an example of accidental circumstances, I am missing the point. A meteor, is that what you mean?

MARTIN: No, for example, one might establish the probability of an earthquake that is supposedly site-specific, it is a determination that has to be made in the licensing of that particular place, and the design, and other requirements. So from the standpoint of being outside of EPA's purview, that was really the function of the regulatory agency, which in this case is the Nuclear Regulatory Commission. The advice of the group was that EPA, as reflected by the group, should stay the hell out of the considerations of accidents in terms of it enunciating them in criteria.

SCHAINKER: Okay, so the criteria should be focused on the end product rather than any site-specific fault zone, or meteor accident, or whatever; its end product minimize risk, improved health and safety, whatever those terms mean, and not focus on the details of a potential accident at any one type of site.

MARTIN: We are just reporting the reflection of the working group.

SCHAINKER: Okay, I just did not understand the sentence as indicated.

MARTIN: Thank you. I think we will have to call this session, or this report, completed. I would like to make one comment. I think you see that there is a tendency here by people who are in the working group who were supposed to have appeared earlier this morning to make these kinds of expressions to the small session to use this larger form for correcting things that probably should have been corrected earlier. We are not behind schedule, but we may fall behind schedule on the longer reports from Groups 2 and 3·if we do the same thing. I would hope there would be more cross-flow between others here who were not in those groups rather than a particular member of the group trying to get a phrase or something changed that he did not like, that he supposedly had an opportunity to accomplish earlier. I think a certain amount of that is tolerable. I did not really pick it up until we got too far into it in this one to really scotch it. I think these things have to be edited and cleaned out and there are going to be consistencies pointed out. I really think it is important to appreciate what did go on here last night. People worked very hard into the night and our contractor, Ecological Analysts, did a marvelous job of taking garbage and getting it into reasonably good format and having a copy for everybody. It took them all night. Without further ado, let us retire this group. You can have a stand-up break if you'd like for about two minutes.

WORKING GROUP 2

RISK CONSIDERATIONS OF RADIOACTIVE WASTE MANAGEMENT

RISK CONSIDERATIONS OF RADIOACTIVE WASTE MANAGEMENT: A STATEMENT OF ISSUES AND OBJECTIVES

Risk, which has been denoted as the probability of radionuclide release times the consequence, constitutes a key issue in the management of radioactive waste. In addition, there is a broader connotation to the issue involving the perception, acceptance, and personal valuation of risks. Measurement and expression of such factors is complicated by whether risk is voluntary or involuntary, individual or group-focused, current or projected, chronic or catastrophic. More extensive discussions of these topics are contained in recent works on risk by Okrent, Rowe, National Academy of Engineering, and Barrager et al. (Refs. 4, 5, 3, 1).

This section identifies three major areas fundamental to the question of risk from the management of radioactive wastes:

1. Methodology for identification and assessment of risk (emphasis on methodology).
2. Risk associated with the management of radioactive wastes (emphasis on product of risk assessment efforts).
3. Incorporation of risk and risk acceptance in decision-making.

Waste management in the context of radiation protection is characterized by several outstanding differences compared with other radiation sources:

1. Risk and costs are probably shared disproportionately by present and future generations, whereas present generations derive the benefits.
2. Balancing of benefit and risk over the period wastes remain toxic is difficult, hence traditional radiation protection standards and underlying philosophies may not be directly applicable.
3. Calculation of risks to present and future generations is clouded in uncertainties stemming from technical limitations in the sciences and engineering and by the very long time-frames over which protective controls are expected to operate.
4. Basic ethical and moral questions permeate the intergenerational risk issue and are not amenable to technical solution.

METHODOLOGY FOR IDENTIFICATION AND ASSESSMENT OF RISK

Ideally, geologic disposal systems and engineered storage facilities or other disposal techniques should be designed and operated to fully contain radioactivity. Practicality, however, may necessitate allowing releases at predetermined levels. Concerns for unplanned releases in the short-term or operational phase are most directly related to mechanical

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failures and human activities involving transportation, site preparation, waste preparation and emplacement, backfilling or covering, etc. In the case of phosphate mining by open pit or stripping, concern in this phase would be with management techniques for water and solids containing radioactivity and with land restoration upon completion of mining. These short-term aspects constitute the principal risk to present populations. There is need to compare risks associated with the operational phase to long-term risks in order to define the principal relationships of cost versus dose versus risk versus benefit, etc., associated with various management options.

Long-term safety (related to the inverse of long-term risk) is directly tied to radionuclide movement from a disposal site and the consequences of such movement. The time-frame of greatest concern commences with cessation of disposal operations and ends when the stored or released radioactivity, if any, is no longer a threat to the populace. Long-term safety must result primarily from natural stability (or at least known and acceptable variability) of geologic, hydrologic, or other processes that might adversely affect wastes. The assessment of such stability can be tested or field-verified to a limited degree beforehand and through early stages of operation. Geoscience evaluations or predictions of what is likely to happen (versus what will happen) seem to be possible for the long time periods over which high-level wastes require containment. However, the adequacy of present-day knowledge of earth processes under natural and waste-affected conditions is of prime concern in predicting the magnitude and timing of future releases. At the bare minimum, envelope or maximum credible event approaches should be utilized. There are other questions and concerns. For example, to what extent should risk assessment be conducted (preliminary or refined)? Are event-tree diagrams and sensitivity studies applicable to disposal concepts which are largely untried or at least unaccompanied by failure statistics?

Lower concentrations of radionuclides are of concern in low-level wastes put into land burial or associated with uranium and phosphate mining and milling. The same fundamental questions and considerations apply, although because the periods over which the radionuclides may be toxic (or in otherwise hazardous concentrations) greatly exceed the operational phase of the disposal facility.

In geologic disposal, failure data for individual components are largely unavailable and therefore the probability of sequential component failure producing a release is also difficult to construct. In light of these deficiencies, the applicability of probabilistic risk assessment methodology to geologic disposal needs to be reviewed.

RISKS ASSOCIATED WITH MANAGEMENT OF RADIOACTIVE WASTE

Risks due to human activities may represent a greater threat to the long-term safety of a repository than has been presented to date by existing waste management practices. The disposal of radioactive waste in an area of mineral deposits (including fuel and water) increases the probability of accidental penetration of the waste containment in the future. It must be assumed that usable mineral accumulations will continue to be sought by future populations, but what minerals or fuels will be sought, the locations, the timing, and the related technology are unknown. Comparison of the last 100 years of the fuels and minerals industries to their last 200 years provides some idea of the dramatic and revolutionary changes in fuel policies and technologies that are possible. Considering the foregoing, risks associated with accidental penetration of waste repositories in mineralized and nonmineralized areas could be difficult to assess.

Besides penetration, other mineral-related impacts affecting the stability of a repository and the migration of wastes therefrom would be even more problematical to predict in terms of occurrence and severity. Perhaps only risk comparisons of repositories in mineralized areas to those in nonmineralized areas are warranted. At issue is the predictability of impacts of human activities in an increasingly technological, mineral-dependent society.

In addition, there is a problem of communication in calculating and comparing risks. For many, if not most people, it is impossible to formulate an accurate concept of a probability of 10^{-6}, and it is also perhaps beyond human comprehension to visualize and actually grasp with our senses and intellect predictions extending millennia and tens of millennia into the future. Therefore, even if technically correct, there is a question whether such mathematical expressions are relevant to the public and the decision makers. Such predictions need to be evaluated and placed in perspective so as not to be misleading.

Evaluating immediate and future risks associated with different waste management concepts so as to determine which concepts have minimal total risk probably requires use of future weighting factors. An obvious question is, Which weighting factor is appropriate? Should future risks be treated as equal to present risks? Should future risks be discounted, as in economic cost comparisons? How is the loss of natural resources in future time-frames valued considering the increasing value of such resources with depletion and burgeoning demands? Are future health effects comparable in value to present ones? How are low-probability, high-consequence events equated to high-probability, low-consequence events?

Perception and acceptance are likely to vary even if the objective (calculated) risks are identical. Recognizing that societal judgments and attitudes, as well as technological judgments, have a role in waste management decisions, there is uncertainty about the proper role or weight to be assigned to each. Risk acceptance by the public and estimated or calculated acceptability for future societies must be significant considerations in the development of alternatives and eventual implementation of a management plan. Preferably, the methodology for risk identification and acceptance should also be publicly acceptable.

On the general question of "unacceptable risks," regardless of the probability of occurrence, a National Academy of Engineering (Ref. 3) committee believed that risks and benefits must be regarded as a continuity, and consideration of incremental changes across the whole range must be part of the analysis.

INCORPORATION OF RISK ASSESSMENT IN DECISION-MAKING

A complex of social, economic, moral, and technical factors surround the risk issue in radioactive waste management. It is likely or reasonable to expect that differences in study findings and dearth of consensus may exist among the technologists working in the area. Measurement of risk and risk acceptance requires an interplay of the physical and social sciences, both of which are faced with serious conceptual and technical limitations and problems. Even if such limitations and problems did not exist, there is an unknown quantity and quality to human behavior wherein man acts, reacts and, in general, responds highly subjectively and perhaps intuitively. Response is often not predictable on the basis of objective, hard-fact inputs alone. If risk could be identified precisely in terms of radionuclide releases and resulting health and environmental effects, there is no certainty as to public and decision-maker acceptance of an implicit or explicit "right" course of action. Recent studies (Starr, Barrager et al., Hammond and Adelman; Refs. 6, 1, 2) have shown that making decisions in the public and political arenas is possible even under such trying conditions.

The role of risk assessment and acceptance methodology in the subject area of nuclear waste disposal calls for more attention as a means to reach an acceptable solution. One school of thought regards the conduct of and output from such efforts as essential to decision-making and somewhat binding as to the latitude allowable. Another viewpoint is that such exercises are always simply one of several inputs to the overall decision-making process. Analysis of risk falls in the category of all mathematical, simulation-related modeling efforts, i.e., a useful, quantitative tool to understand a complex system in terms of input, output, and functional interactions. It may be a systematic approach to simultaneously or at least sequentially examine a large and diverse data base, often characterized by measurements of dissimilar type, accuracy, and significance to the processes of interest.

Identification of risks and acceptable levels of risk, as may be incorporated in an active waste management program, is not subject to rigorous, objective proof. A multiplicity of study methods may be necessary to examine risk and risk acceptability. Decision making from such studies and other considerations should seek some balance of the risk issue with other aspects such as technical feasibility, present and future social acceptance, and economics. In view of these considerations, must acceptable geologic disposal alternatives incorporate retrievability options? Should disposal programs have minimal short-term risk with provision for cessation or modification of a disposal program if changed conditions warrant and if retrieval can be justified on economic, societal, short- versus long-term risk considerations, etc? Inadequate performance and/or availability of new, improved alternatives must be recognized in the retrievability issue.

The criteria and methods used to determine socially acceptable risks should be explicitly developed and reviewed by originating agencies and the public and other private sectors affected by risk-related decisions. Actions with particularly long-term implications should be undertaken or permitted only after study of the alternatives and associated risks, benefits, and acceptability in the context of possible future shifts in values (Ref. 3).

SUMMARY OF CONSIDERATIONS

In summary, the following issues are appropriate to the consideration n risk in the development of environmental criteria and standards for radioactive waste management. As such, they shall be included among the topics to be examined in this Workshop:

1. Should the probabilities and/or consequences of abnormal or unplanned events associated with radioactive waste management plans be considered in the development of criteria and standards? If so, in what manner?
2. The time-frames of interest in the management of transuranic radioactive wastes are larger than those associated with any previous risk analysis. In addition, a number of geological disposal systems are now largely conceptual and unaccompanied by failure statistics. Considering these facts, to what extent should quantitative risk analysis of long-lived radioactive waste management plans be attempted in support of environmental criteria and standards? What about other categories of radwaste?

3. When quantitative analyses are to be made of the risk, what analytical methods should be applied to various phases associated with waste management (i.e., transportation, repository operations, retrievable storage, ultimate long-term disposal, etc.)?
4. Given that appropriate methods have been selected, what data should be considered in quantifying the probabilities and consequences of abnormal or unplanned events?
5. What consequences are of concern in the risk assessment? For example, should the analysis be restricted to health effects of the types considered in the Reactor Safety Study? Or should questions such as the risks of compromising future resources of valuable minerals be considered?
6. Can one reasonably predict throughout the time-frame of interest what resources might be considered valuable? Can one assess the possibility of radioactive releases being caused by penetration of a repository by persons pursuing mineral resources?
7. How should the acceptability of the risks associated with radioactive waste management be determined?
8. Regardless of the types of consequences that are considered, how should future risks be equated with present risks?
9. How should the risks from low-probability, high-consequence events be valued in comparison to the risks from high-probability, low-consequence events?
10. If risk assessments are performed, should an environmental criteria for irretrievable geological disposal be established that allows such disposal only when the risks are reasonably quantifiable through the period of significant waste radioactivity? Should retrievability of stored radioactive waste be required until such time as enough data have been collected to make such reasonably quantitative risk analyses?

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RISK ASSESSMENT METHODS FOR NUCLEAR WASTE MANAGEMENT SYSTEMS

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INTRODUCTION AND SUMMARY

Radioactive waste is generated in a variety of forms by operations in the nuclear fuel cycle. Numerous management systems have been devised to immobilize and isolate these wastes. Such systems include multisite processing operations, transportation, and storage/isolation.

Evaluation of waste management systems is a complex process. Assessments of proposed systems involve consideration of technical feasibility, research and development needs, timing, cost, national and international policies, environmental impact, and both the calculated and the publicly perceived safety.

Risk analysis is a method of assessing the safety of proposed systems. Through such an analysis, consequences of postulated releases of radioactive material can be placed in perspective by viewing the events relative to their probability of occurrence.

This paper reviews risk assessment methods and their potential application to nuclear waste management systems. Previous and ongoing studies on the risk/safety of high-level waste management systems are discussed along with their limitations and potential improvements.

BACKGROUND

In general, a risk analysis of a nuclear related system consists of the following basic steps:

1. Definition of the inventory of radioactive material and its containment/confinement barriers
2. Identification of potential failure modes
3. Estimation of the probability and amount of radioactive material released by the potential failure modes

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4. Analysis of the consequences of the radioactive material released
5. Estimation of the system risk.

Figure 1 shows the information flow and calculational steps for a typical risk analysis. More detail is given in the following section.

GENERAL RISK ASSESSMENT METHODS

Various approaches for performing risk analyses have been developed. These methods are discussed as related to two major areas of risk analysis: (1) analyses of potential release sequence probabilities; and (2) consequences analysis.

ANALYSES OF POTENTIAL RELEASE SEQUENCES

Included in this category are the identification of the potential release sequences and the estimation of their probabilities for the system studied. The release sequences can be postulated directly, derived by inductive ("what happens if?") techniques, or deductive ("how can something happen?") techniques. Some of the techniques available include hazards analysis, failure modes and effects analysis, decision trees (event trees), and fault trees. A good survey of these methods is given by H. E. Lambert (Ref. 2). Each approach has its advantages and limitations and often a combination of techniques is advantageous.

Methods discussed in this paper include: event trees alone; event trees with fault trees used to supply most of the branch probabilities (Ref. 3); the similar cause consequence analysis (Refs. 4, 5) in which a fault tree feeds into an event tree through a common critical event and in which fault trees again supply most of the branch probabilities; and various fault-tree techniques.

Inductive methods such as event trees (Refs. 2, 3) start with an assumed initial failure. Additional component failures required to obtain a release (system failure) are then identified. Fault-tree analysis (Refs. 2, 6) is a deductive process. The analyst assumes the occurrence of an event selected as the top, undesired event as constituting system failure. He then systematically works backward to identify component faults that could cause or contribute to the undesired events. Brief summaries of three recent approaches for analysis of potential release sequences are given below. A more detailed treatment is given in Appendix A.

Event Tree - Fault Tree

Combinations of an initiating event and the response of the various engineered safety features are modeled on event trees. The probabilities of key events in the event trees are

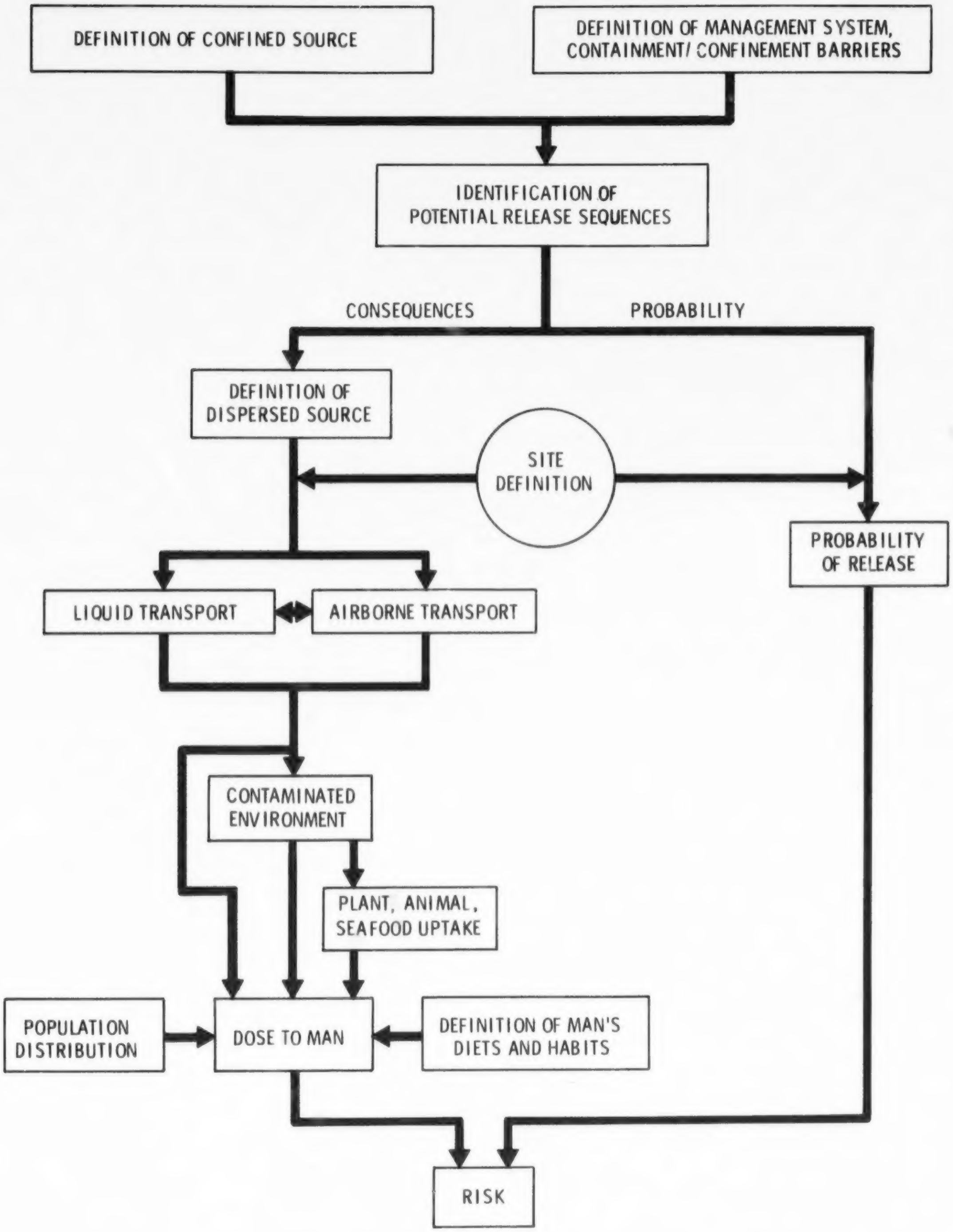
DEFINITION OF CONFINED SOURCE
DEFINITION OF MANAGEMENT SYSTEM, CONTAINMENT/ CONFINEMENT BARRIERS
IDENTIFICATION OF POTENTIAL RELEASE SEQUENCES
CONSEQUENCES
PROBABILITY
DEFINITION OF DISPERSED SOURCE
SITE DEFINITION
PROBABILITY OF RELEASE
LIQUID TRANSPORT
AIRBORNE TRANSPORT
CONTAMINATED ENVIRONMENT
PLANT, ANIMAL, SEAFOOD UPTAKE
POPULATION DISTRIBUTION
DOSE TO MAN
DEFINITION OF MAN'S DIETS AND HABITS
RISK

Figure 1. Risk analysis calculation flow (Ref. 1).

evaluated by means of fault trees. Each key event is defined as the top, undesired event of a fault tree (Ref. 3).

Cause-Consequence Diagram

The cause-consequence diagram is similar to the event tree - fault tree method. A critical intermediate event is selected for study. Preceding events are analyzed by fault-tree analysis with the critical event being the top of the fault tree. Events subsequent to the critical event are handled by event trees (Ref. 5).

Fault-Tree Method

A large fault tree is drawn with the top event being release from the facility. This fault tree traces the flow of radioactive material through the system (usually a facility or major operation) and all the events within the system appear on the same fault tree. An event tree type of treatment is used to model environmental transport and human exposure. The binary limitation of fault trees (i.e., faults must be "on-off") is circumvented by treating each release sequence (cut set) separately and using a distribution of releases where necessary (Refs. 7, 28).

The probabilities of the identified release sequences must be calculated, as little or no statistical data are available. Probabilities for the release sequences can be obtained from estimates of the frequency of each component fault within the release sequence. Sources of informaiton for assigning fault probability values are: (1) experience with the component or similar components, (2) testing, (3) engineering analysis, and (4) engineering judgment. Care must be taken to account for any potential dependency among component faults in the release sequence.

The basic approaches described have both common and separate strengths and limitations. A major limitation is that no method can assure that all potential release sequences have been identified. A physically realizable sequence may be omitted because of simplification, oversight, lack of understanding of the system, or inability to envision all possible sequences. Other basic limitations are the necessary data requirements, potential dependencies (common cause failures), and difficulties in modeling potential human interaction with the system.

The fault-tree approach (Ref. 7) has some advantages and weaknesses when compared with the similar event tree and cause-consequence analysis. No assumption of an initiating event or a critical event is necessary in the fault-tree method. This is an advantage for systems where the key initiators are not known. Other possible advantages include more direct treatment of common cause failures because all events appear

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on one fault tree, and potentially a more complete analysis because the system is treated as a whole. A disadvantage of this approach is the required analysis of very large fault trees.

The event tree and cause-consequence analysis better facilitate and display the detailed analysis (particularly time phasing) of accidents involving a common initiating critical event. Using these techniques a complex problem can often be divided into manageable segments. However, there is a disadvantage in that there is no formal procedure to develop the required key initiating events and no formal construction procedures for the event trees or cause-consequence diagrams themselves. Difficulties often arise in the ordering and the treatment of dependencies of the branch operators (key events or decision points in the event trees or cause-consequence diagrams).

Most safety analysts will agree that there is no best method. A combination of the above complementary approaches is often advantageous. A fault tree would be used as indicated above to provide the most comprehensive coverage of potential accidents and to separate those of prime interest. Detailed analysis of such classes of accidents could follow by means of event trees or cause-consequence analyses. If the key initiating events are known with confidence, the comprehensive type of fault-tree analysis may not be necessary.

CONSEQUENCE ANALYSIS

For nuclear systems, risk analyses consequences have typically been analyzed in terms of amount of radioactivity released, dose, health effects, and property damage.

The consequence analysis is usually accomplished in two stages. The amount and physical-chemical characteristics of the radioactive material released from the identified release sequences are estimated. Then the transport of this release by various pathways through our environment and the resulting consequences to man and the environment are examined. Both of these stages often require complicated mathematical modeling and are subject to large uncertainty.

The first stage is very specific to the system studied and general models have not been developed. The type of information required includes volatility, solubility, and frangibility data for the form of radioactive material in the system under study, the degree of confinement system failure, and transport and deposition of the release within the facility. The basic sources of required information are existing experimental data, test programs, engineering analysis, and engineering judgment.

Several general models exist for analyzing the transport of radioactive material in the environment. Major pathways include atmospheric, groundwater, and surface water transport. The output of these models is combined with dose models which calculate the resultant dose to man. Strenge et al. (Ref. 8) review the strengths and limitations of calculational models and computer programs for evaluating the dose assessment of radioactive releases. Figure 2 shows the consequence model used in WASH-1400 (Ref. 3). The details of the atmospheric pathway and the dose assessment models are not discussed here and the reader is referred to the two references mentioned above.

Risk assessment of nuclear operations sometimes requires analysis of groundwater pathways (Ref. 9). Marino (Ref. 30) reviews the literature in this area. A unified computerized model of geosphere (Refs. 10-12) and biosphere (Refs. 13, 14) transport has been developed (Ref. 15). For chains of radionuclides des cursors and decay products) the equations developed for transport through geologic media include effects of convection, diffusion, sorption, and generation and decay. Simultaneous solutions of equations for all precursor radioisotopes as well as for the chain member of interest are obtained. Solutions have been obtained for both impulse and band releases. Transport through both salt and nonsalt media has been studied. Typical results of geosphere transport analysis appear in Burkholder et al. (Ref. 15). The geosphere transport model links with the biosphere model (food chain, etc.) at the point where the radionuclides enter a body of surface water or an underground well.

If the consequences from a radioactivity release sequence are expressed in terms of dose, there are three possible outputs: (1) individual dose, (2) population dose, and (3) environmental dose. In past risk analyses relatively little quantification has been done of the environmental dose commitment. This dose commitment represents the sum of all doses to individuals over the time period during which the released material remains in the environment in a state available for interaction with humans (Ref. 16). This concept, as suggested by the Environmental Protection Agency (EPA) (Ref. 29), needs consideration.

By use of the techniques described by the U.S. Atomic Energy Commission (U.S. AEC) and the National Academy of Sciences, National Research Council (Refs. 3, 17), the calculated dose commitments can be combined with estimates of the health effects from individual and population exposure to radiation.

Knowing both the consequences and the probability, a risk expression can be generated. The most general definition of risk is that it is some function of the probability and the consequences of a release sequence. A frequently used definition of risk is the product of the anticipated frequency of a

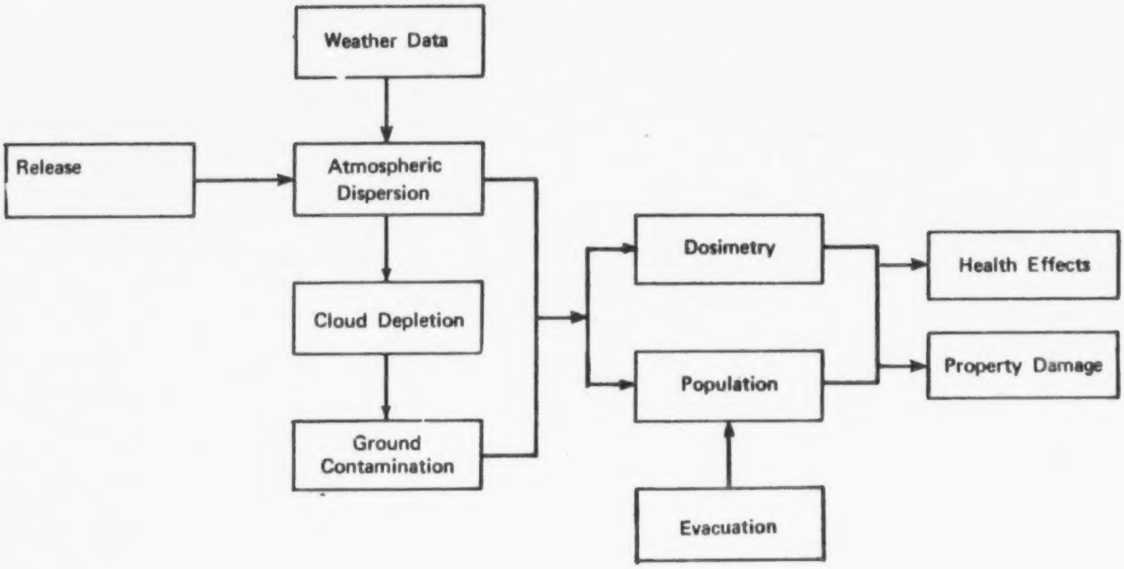
Weather Data
Release
Atmospheric Dispersion
Cloud Depletion
Ground Contamination
Dosimetry
Population
Evacuation
Health Effects
Property Damage

Figure 2. Outline of consequence model (Ref. 3).

release sequence and its consequences. That is, risk is the mathematically expected consequences of a release sequence. Recognizing the subjective nature of risk and its perception by the public, many studies (Refs. 3, 7, 16, 18) have avoided the use of a specific risk expression and simply report curves of probability versus consequences.

As indicated in the above discussion of risk assessment methods, various degrees of sophistication of method and output are possible. Safety analysis programs have different objectives and different constraints on time (work completion date) and cost. They therefore differ in breadth and precision of analysis. Some programs involve existing systems with a great deal of applicable system definition and safety-related data. Safety/risk analyses of these systems can be performed in considerable depth and with good accuracy if time and cost constraints are not severe. On the other hand, studies made during conceptual phases of system design preclude detailed analysis. Other things being equal, the later in the system life-cycle the study is performed, the more information is available and the greater the accuracy of the results. However, the sooner the analysis is made, the easier it is to effect any safety-related changes in the system under study or its conceptual design. A trade-off is involved between the timeliness and the depth of accuracy of the analysis. Other programs require a trade-off between the cost and the depth and accuracy of analysis. A variety of analytic methods and data retrieval systems is needed to satisfy the particular requirements of different safety analysis programs.

APPLICATION OF RISK ASSESSMENT METHODS TO NUCLEAR WASTE MANAGEMENT SYSTEMS

Nuclear waste management operations are divided into two stages: (1) the short-term operating steps, and (2) long-term isolation. A typical system for high-level waste is given in Figure 3. The discussions in this section will deal strictly with high-level waste. However, much of the information given can be analogously applied to other waste streams. Figure 4 shows the other potential waste streams of the light water reactor (LWR) fuel cycle.

SHORT-TERM WASTE MANAGEMENT OPERATIONAL ACTIVITIES

For high-level waste management, short-term operational steps include three phases at a reprocessing plant (liquid storage*, solidification and canning, and solid storage); transportation; possible interim storage; and emplacement operations at a geologic repository.

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* Liquid storage is planned to be minimized.

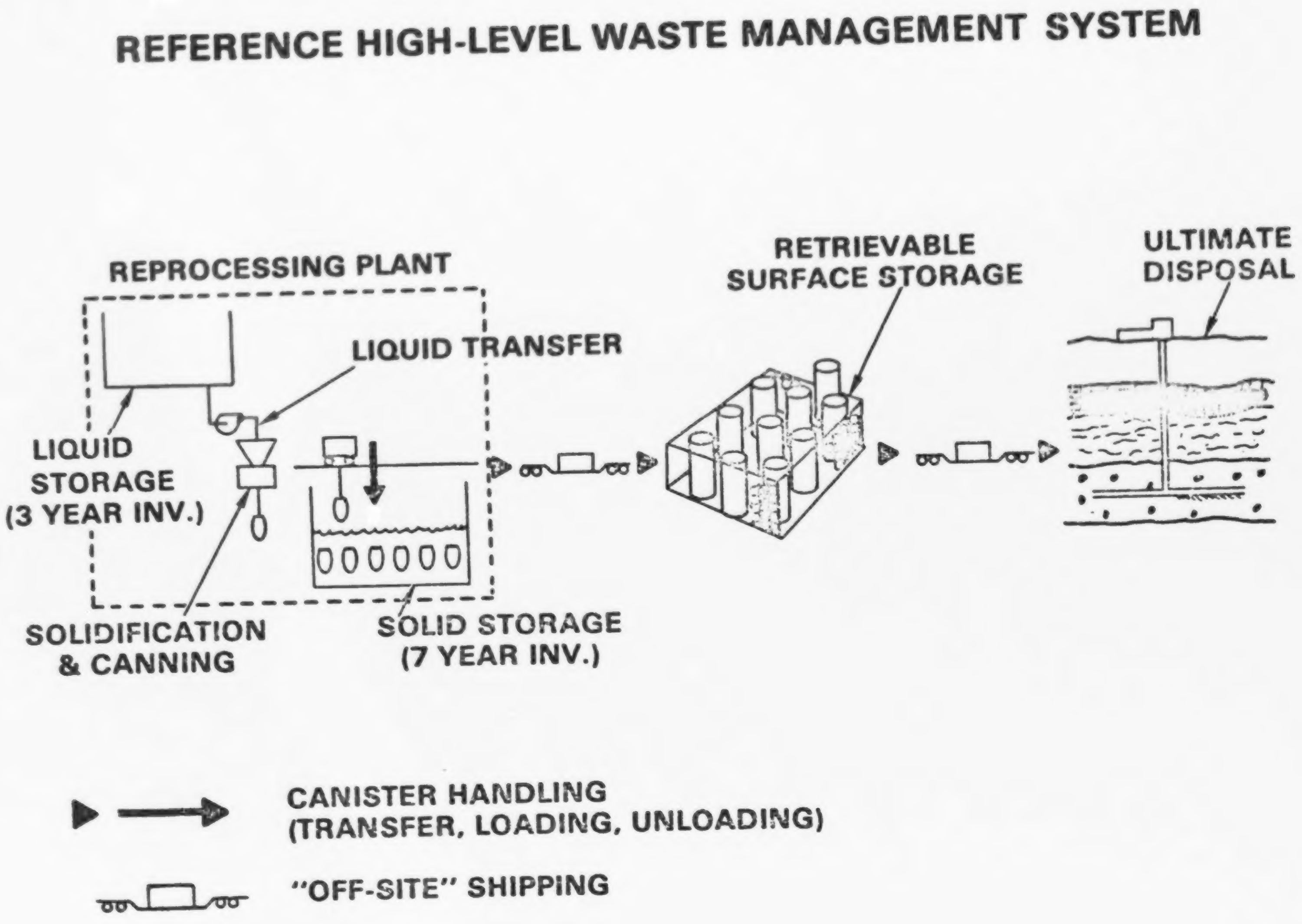
REFERENCE HIGH-LEVEL WASTE MANAGEMENT SYSTEM
REPROCESSING PLANT
LIQUID TRANSFER
LIQUID STORAGE (3 YEAR INV.)
SOLIDIFICATION & CANNING
SOLID STORAGE (7 YEAR INV.)
RETRIEVABLE SURFACE STORAGE
ULTIMATE DISPOSAL
CANISTER HANDLING (TRANSFER, LOADING, UNLOADING)
"OFF-SITE" SHIPPING

Figure 3. Reference high-level waste management system.

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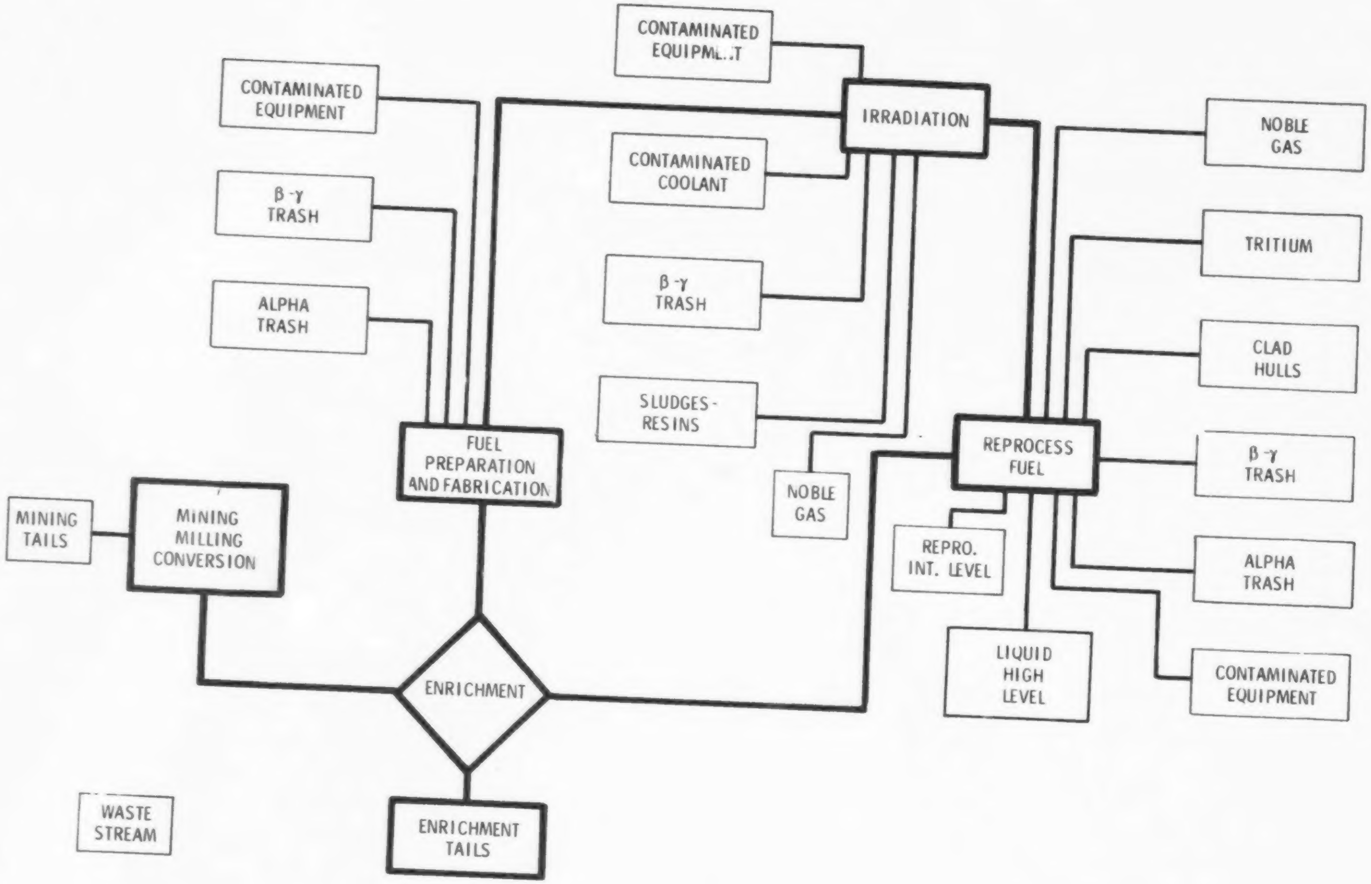
CONTAMINATED EQUIPMENT
β-γ TRASH
ALPHA TRASH
FUEL PREPARATION AND FABRICATION
MINING TAILS
MINING MILLING CONVERSION
ENRICHMENT
ENRICHMENT TAILS
WASTE STREAM
CONTAMINATED EQUIPM..T
IRRADIATION
CONTAMINATED COOLANT
β-γ TRASH
SLUDGES-RESINS
NOBLE GAS
REPROCESS FUEL
REPRO. INT. LEVEL
LIQUID HIGH LEVEL
NOBLE GAS
TRITIUM
CLAD HULLS
β-γ TRASH
ALPHA TRASH
CONTAMINATED EQUIPMENT

Figure 4. Potential LWR fuel cycle wastes.

The basic methods described earlier have direct application to these short-term operating phases. Safety/risk analyses of waste management system operations have been performed to various depths; however, none has been attempted at the detailed level comparable to WASH-1400 (Ref. 3).

McGrath (Ref. 19) reviewed waste management strategies and discussed risk and risk reduction. Detailed analyses were not performed, but an interesting approach was presented based on an expected risk criterion. Using this criterion and postulating upper limit consequences for liquid waste storage, waste solidification, and solid waste storage, he estimated permissible upper limit accident probabilities. The conclusion was that the most stringent safety requirements apply to liquid waste storage.

Studies are in progress at Battelle, Pacific Northwest Laboratories (Ref. 20) using the fault-tree method described earlier for a conceptual high-level radioactive waste management system. This system is assumed to consist of operations involving (1) liquid storage, (2) solidification, (3) water basin storage, (4) rail transport, and (5) retrievable surface storage.

Dominant failure sequences for the accidental release of radionuclides have been tentatively identified for the various activities of the reference system. Dominant sequences are defined as those with the highest mathematical product of probability and consequences, the latter in terms of quantities of waste released. The initial assessment revealed that dominant scenarios that could conceivably have significant public health and safety impact are highly improbable, e.g., on the order of 10^{-6} per year of operation.

Accidental releases of radioactive material initiated by both process operating events and events external to the plant (e.g, earthquakes) were found to contribute to total system risk. Except for the mechanically or electrically induced interruption of cooling water to stored liquid and solidified waste, postulated release scenarios contributing the bulk of the risk generally involved sequences intitiated by external events.

Dominant scenarios with conceivable significant public health and safety impact were associated with the passive storage activities rather than with the relatively active modes of solidification and transportation. This is primarily due to the large radionuclide inventories associated with the storage activities. Dominant scenarios were associated with airborne pathways.

Reevaluation of this initial assessment is underway to ensure that insights obtained by comparisons are valid. Areas of future work include: (1) performing sensitivity studies,

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(2) establishing error bounds, and (3) performing more detailed analyses on the dominant potential release sequences.

Smith and Kastenberg (Ref. 16) give a background discussion on risk analysis and waste management and perform a brief risk analysis for extraterrestrial disposal and interim surface storage. The release scenarios analyzed were postulated directly and the results indicate, within the assumptions used, that the risks of these management schemes are small compared with that of natural background radiation.

Several basic problem areas exist in assessing the risk of the operational steps in waste management systems. An important one is perhaps the lack of direct and readily available data. In the performance of safety analyses of conceptual high-level waste management systems, information gaps will be encountered. This is expected, as there has been little operating experience for high-level waste management activities. Only a relatively small amount of experimental work has been done in identifying and analyzing the consequences of potential accidents.

The basic information needs for improving existing safety assessments and their usefulness can be placed in the following closely related categories: (1) Additional information on the probability of breaching containment/confinement barriers versus the severity of the breach; (2) data on the quantity, transport mechanism, and the chemical-physical form of the radioactive material released from failed barriers; (3) more information on system characteristics and interactions in the accident environment; and (4) more information characterizing the solidified high-level waste form.

Another factor that limits the detail and accuracy of risk assessments of waste management operational steps is the conceptual nature of present designs. This results in a limited treatment of common cause failures and human error. It also results in difficulties in treating severe external environments (e.g., earthquakes).

LONG-TERM WASTE ISOLATION

Present programs in the United States and elsewhere for commercial high-level waste are aimed at isolation in deep geologic formations. To assess the risk of a geologic repository, methods must account for a spectrum of events that could cause loss of geologic integrity and subsequent adverse consequences. Four types of potential causes of loss of isolation have been identified:

1. Sudden natural events such as meteorite impact
2. Geologic processes such as faulting or ice ages

3. Changes in local geology caused by creating the repository and by introducing thermal and radiation sources
4. Human intrusion.

Some safety assessments have been made in each of the above categories. Approaches based on probabilistic techniques, consequence analysis, risk analysis, and hazard indices have all been used. Work remains, however, to expand the scope of the studies and to evaluate past assessments. The factors involved pose difficult challenges and clearly demand assessment techniques beyond those conventionally used. Some of the unique challenges anticipated include:

1. Consideration of geologic mission times and slow geologic processes
2. Consideration of events where the resulting radiological consequences could be delayed by hundreds of year
3. Consideration of events that are orders of magnitude less likely to occur than those normally associated with what could be termed major accidents
4. Consideration of natural events so catastrophic that the release of radioactive material as the result of loss of geologic isolation could be of secondary concern
5. The use of existing radiological consequence (pathway) models for estimating dose to far-future generations
6. The use of assessments where results are not subject to demonstration
7. Consideration of life styles and technological capabilities of future civilizations
8. The need for effective communication of information on risk situations that could be beyond current human cognition and perspective.

The above considerations make it difficult to apply the risk analysis methods discussed earlier to geologic isolation. A major problem is the absence of predictive data and the fact that the application of failure data (rates) and radiological consequence (pathway) models to the very long time periods involved can become highly speculative.

The above concerns do not necessarily imply that existing risk analysis methods will be without value in evaluating the safety of geologic isolation activities. Fault trees can be used in the systematic identification and graphic illustration of factors that could cause the accidental release of radionuclides. Schneider and Platt (Ref. 21) present a generic fault tree related to geologic concepts.

Most past safety studies of geologic isolation have analyzed either the probability or the consequences of selected potential release sequences. No in-depth systematic studies have been performed.

Claiborne and Gera (Ref. 22) analyzed selected containment failure mechanisms and their consequences for a bedded salt repository. Causes of containment failures examined included drilling through the geologic disposal formation, impact of a meteorite, volcanic activity, a fault intersecting a repository, sabotage, nuclear warfare, increase in salt dissolution rates, and waste disinterment by erosion of the overburden. The primary conclusion was that a serious breach of containment for such a repository is only a very remote possibility. Consequence estimations were made only for a meteorite impact. Probability estimates were given for meteorite impact and for faulting. Other events were analyzed qualitatively.

Gera and Jacobs (Ref. 23) gave a qualitative discussion of natural geologic processes relevant to waste disposal. These include faulting, erosion, leaching and transport by groundwater, and plastic deformation of the disposal formation.

The toxicity or hazard index approach has been used to assess the potential consequences of geologic disposal. From the concept of maximum permissible radionuclide concentrations in water, a typical Relative Hazard Index (RHI) can be defined for radionuclide i:

$$(\mathrm{RHI})_i = \frac{Q_i}{(\mathrm{MPC}_w)_i}$$

where Q_i is the radioactivity in curies of radionuclide i, and $(\mathrm{MPC}_w)i$ is the maximum permissible concentration of radionuclide i in drinking water (curies/m^3) (Ref. 24). The total RHI of a mixture is the sum of the $(\mathrm{RHI})_i$'s. Several authors have used this or a modified hazard index approach (Refs. 16, 19, 25, 26). Hamstra (Ref. 25) has shown that after a few hundred years the waste from a metric ton of spent pressurized water reactor (PWR) fuel presents a smaller total hazard than that of the ore required to produce the fuel.

The limitations of the hazard index approach include the inability to take into account waste form and insolubility, storage facility design, remoteness from man's environment, food chain buildup, or even the pathway into the water supply (Ref. 27). It is only a measure of potential hazard under 100 percent transport conditions.

A more detailed consequence analysis approach is that by use of transport models. Burkholder (Ref. 15) has developed one such model that can be applied to geologic repositories. The basic features of this model were discussed earlier in the section on consequence analysis. Nuclide release to an underground water stream that flows directly through the geologic medium to a surface water body was assumed. The time of release initiation, the nuclide release rate, and the migration distance to the biosphere were parametrically varied. Sorption equilibrium is assumed at all points along the migration path. Doses were calculated for a maximum individual and the results of this study show that for reasonable storage conditions, the potential incremental radiation doses would be of the same order as, or less than, doses from natural sources.

Additional work is required in both release sequence analysis and consequences analysis for geologic repositories. At this point in time a detailed probabilistic risk analysis (i.e., WASH-1400) of geologic isolation does not seem feasible. However, basic methods are in place to assist in identifying potential release sequences and in estimating probabilities and consequences. Analyses can be performed for specific release sequences of concern, drawing on existing data and extrapolation of past experience. The degree of confidence in the results depends on the availability and applicability of data and the validity of the extrapolations.

CONCLUSION

Methods and background information from previous studies are available to assist in quantifying the risk of waste management systems. The degree of detail in any risk analysis is limited by the conceptual nature of many waste management systems, lack of detailed failure data, and by the special problems encountered with geologic isolation. Risk methods continue to evolve and research and development programs are being established to supply needed information. Table 1 summarizes some ongoing work on the safety of high-level waste management.

Potential benefits from a systematic risk assessment of waste management systems incude: (1) systematic identification of conceivable failure modes, (2) development of perspective on the relative safety of system components, (3) identification of research and development needs for supplying missing data, (4) preliminary input for management decision-making and improved system design, and (5) establishment of a rational basis for choosing between alternative waste management systems.

Table 1. Ongoing Safety Studies of High-Level Waste Management

Study	Sponsoring Agency	Contractor	Lead Individual
Radioactive Waste Management Systems Model	EPA	Univ. of New Mexico	S.E. Logan
Technical Support for Environmental Radiation Protection Standards Concerning High-Level Radioactive Waste Management	EPA	(RFP Recently sent out)	
Environmental Survey of the Reprocessing and Waste Management Portions of the LWR Fuel Cycle	NRC	Task Force	
Determination of Performance Criteria for High-Level Solidified Nuclear Waste	NRC	LLL	Jerry Cohen
Risk Methodology for the Evaluation of Radioactive Waste Disposal	NRC	Sandia	P.E. McGrath
Waste Management Studies	ERDA	PNL	J.W. Bartlett
Waste Management Safety	ERDA	PNL	L.D. Williams
Waste Isolation Safety Assessment	ERDA/OWI	PNL	G.J. Dau
Generic Waste Management EIS	ERDA	PNL	C.M. Unruh
Transportation Safety Studies	ERDA	PNL	L.D. Williams
Alternatives for Long Term Management of Defense Waste	ERDA	Hanford, Savannah River & INEL	

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APPENDIX

THE WEB OF EVENTS

Figure A-1, a simplified diagram of the generalized web of events for facility release sequences, facilitates comparing the methods reviewed for sequence identification (Ref. 7). The points in Figure A-1 represent types of events, some of which are linked by lines to indicate a nonzero probability of occurring in the same release sequence. Time increases along the horizontal coordinate. The vertical coordinate provides a way to plot distinct types of events.

Across the top of the diagram are listed five general classifications of events as they might occur in a release sequence. Initiating events are typically those leading to exposure of the primary containment of the radioactive material to severe mechanical, thermal, and/or chemical environments. For example, a loss of cooling accident for water basin storage of encapsulated, solidified waste might involve power outage, pump failures, pipe failures, or various combinations of these.

Next are the types of events that actually negate the primary containment, resulting in release of radioactive material within the facility. Examples are waste canister failure or, for a liquid source, a vessel breach.

The events related to a release from a facility are those that might occur immediately following the failure of primary containment. They typically involve passage of radioactive material through various segments of the ventilation or off-gas systems, culminating in exit from the building. Thus, the first three categories involve events occurring almost exclusively within the facility.

The last two categories involve events that generally occur outside the facility. Events related to the environmental transport and deposition of the radioactive material are governed primarily by conditions such as weather and topography near the facility. Considerations such as land use factors lead into the final classification, irradiation. This involves events of actual exposure, influenced chiefly by population density and radiological factors.

HOW VARIOUS SYSTEMS SAFETY METHODS HANDLE THE WEB OF EVENTS

Listed down the left side of Figure A-1 are several ways of studying the release sequences. Model A is intended to indicate the total web of possible events. Models B, C, D, and E indicate four ways of dividing the problem into smaller pieces, to be followed by integrating the web back together so as to obtain the total result.

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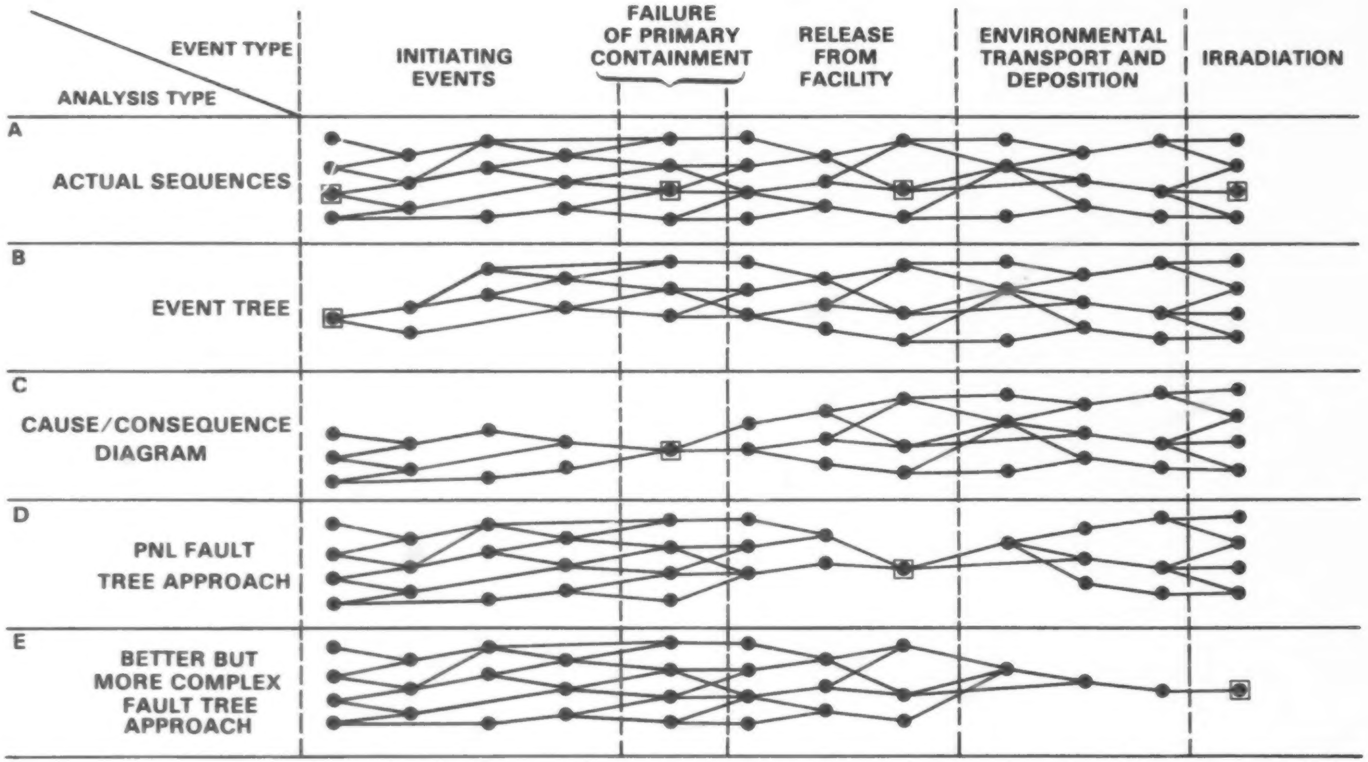
EVENT TYPE
ANALYSIS TYPE
INITIATING EVENTS
FAILURE OF PRIMARY CONTAINMENT
RELEASE FROM FACILITY
ENVIRONMENTAL TRANSPORT AND DEPOSITION
IRRADIATION
A
ACTUAL SEQUENCES
B
EVENT TREE
C
CAUSE/CONSEQUENCE DIAGRAM
D
PNL FAULT TREE APPROACH
E
BETTER BUT MORE COMPLEX FAULT TREE APPROACH

Figure A-1. A simplified diagram of the generalized web of events for analysis of accidental releases from facilities.

In Model B, which is intended to illustrate the event-tree approach, one of the mutually exclusive initiating events (the point enclosed by the box in Model A) is followed along a widening path to the final events. For analysis of loss-of-cooling accidents, a pipe break might be selected as an initiating event (Ref.3).

Model C is an attempt to depict a typical application of cause-consequence analysis. One of the mutually exclusive intermediate events involving or preceding release of radioactive material from primary containment is selected for study. All paths leading to this event, termed the "critical" event, are analyzed by fault-tree analysis. The critical event is the top event of the fault tree. All subsequent events are handled as in the event-tree analysis of Model B. The problem is neatly divided into two parts, the interface being the selected critical event.

If, in the example for Model B, a pipe break were the result of preceding initiating events, then the analysis would probably be performed as in Model C. In both methods, the event tree branch probabilities are often obtained by means of separate fault trees. The top events of such fault trees are the branch events or decision points.

Model D represents a Pacific Northwest Laboratories (PNL) fault-tree technique. Each mutually exclusive, terminating point for Model A related to a release from a facility is "clipped" or isolated. Events leading to and proceeding from each point are analyzed. The two parts of the web are then rejoined to give the total flow of events.

In the application of Model D, the system fault tree is drawn with the top event representing a release from a facility by any pathway. The mutually exclusive interface events described in the preceding paragraph are generally drawn as the next-to-top level events. They represent the various release modes out of the final containment barrier(s). Examples are airborne release up the stack, airborne release through the walls of the building, and release into a stream. The preceding events related to a release from a facility represent the flow of radioactive material through the ventilation and off-gas systems of the facility. These events, as well as the primary containment failure events and the initiating events, all appear on the same fault tree. Following the interface events, an event tree type of treatment is used to model environmental transport and deposition of the material and human exposure.

The prerelease (from the facility's outer barrier) occurrences generally involve electrical, mechanical, and/or chemical events related to engineering. Postrelease occurrences generally involve environmental and biological events associated with those scientific disciplines. If a complete set of

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mutually exclusive events (consisting of the release of certain types of radioactive materials in certain modes) can be determined and the probability and radiological consequences of each type of release calculated, then a value of risk can be estimated.

In Model E, one of the mutually exclusive final events is selected for study. All paths leading to it are studied by means of fault-tree analysis.

SELECTION OF A SYSTEMS SAFETY METHOD

A potential weakness of any systems safety method exists in the process of uncoupling the web of events, performing independent calculations on these segments, and then recoupling. Interactions among the uncoupled portions of the web are easily overlooked.

The approaches of Models B and C are vulnerable to interactions occurring within the facility. In Model C, the uncoupling occurs within the facility. In both Models B and C, the use of separate fault trees to develop the branch probabilities of the event tree could result in missed interactions between basic events in different fault trees. For example, a fire that fails the primary containment might also lead to failure of the ventilation system. Extreme caution is required in these methods to guard against missing such common-cause failures.

An advantage of Model D over Model C is that in-facility events are treated on the same fault tree rather than on several fault trees and an event tree. This tends toward a reduced possibility of overlooking in-facility common-cause failures. The disadvantage is a more complex fault tree.

Model E may be the most rigorous model, at least on one point: in progressing from Model C, to D, to E, the top event of the fault tree comes closer to our ultimate interest--exposure of man. Also, Model E guards against undiscovered coupling between prerelease and postrelease events, to which the other models are vulnerable. Examples of such events are earthquakes, which could alter aquifers in the release area, and tornadoes, which could temporarily alter local meteorology. Unfortunately, Model E is generally too complex to be considered currently feasible.

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ECONOMICS OF RADIOACTIVE WASTE DISPOSAL

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The Environmental Protection Agency (EPA) is under substantial pressure to promulgate regulations for secure storage of radioactive waste. This pressure is in part from the biophysical risks of temporary storage in admittedly inadequate facilities, and is in part a response to successful citizen intervention that demands acceptable waste disposal as a precondition to further nuclear power plant licensing.

The government has responded to these demands by mandating strict timetables for health regulations, site identifications, and disposal facilities development. This paper addresses the economic implications of waste disposal on utility choice of new power plants and the substantial uncertainty that secure storage can be developed on a prescribed timetable.

ECONOMICS OF EXISTING AND ANTICIPATED RADIOACTIVE WASTE

For existing radioactive waste, prudent and economic disposal is determined by the balancing of cost and benefit. The benefit is measured by the reduction in risk achieved by isolation from the biosphere. Because the consequences of waste dispersal are so serious, it is anticipated that extraordinary engineering efforts will be employed. If the best available disposal merely meets minimum standards of safety, very little economic trade-off will occur. In any case the selection of the first disposal site will probably occur before a large inventory of comparable and possibly superior sites are identified.

Economic analyses of waste disposal from operating nuclear power plants, and particularly from planned nuclear plants offers a much broader set of choices. In this case the analysis can identify changes in each step of the fuel cycle (from uranium mining to radioactive waste disposal) such that total costs of delivering electricity are minimized. For example, Kubo and Rose (1973) and Rose (1974) suggested that reprocessing could reduce long-term radioactivity by a factor of 100 at a cost of 0.02¢/kWh. If this were less expensive than achieving the same level of safety through more protective storage, it is in the interest of economy to encourage that processing.

The full spectrum of fuel cycle choices is influenced by assumptions about the cost of waste disposal. For instance, the design of the reactors assumes a certain price and avail-

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Table 1. Cost Incidence Categories of Power Plant Assessment

I. Costs Included In Utility Estimates of Electricity from New Plants

- A. Direct Financial Costs of Capital, Fuels, and Management Paid by Electricity Consumers
  1. Residential
  2. Commercial (Direct financial costs of capital, fuel, labor and other operating expenses including return to utility stockholders)
  3. Industrial

II. Costs Paid By American Society but not Included in Public Utility Estimates

- A. Utility, Utility Supply Industry and Resource Owners(1) (cost overruns, utility cost of faulty plants before inclusion in rate base, equipment supplier cost overruns, and inability to recover research expense, loss to landowners whose land is condemned and purchased at less than nuclear site value, uncompensated restrictions on land use adjacent to plants, costs of delay from political controversy, etc.)
- B. Public
  1. Federal taxpayers(2) (research, technical assistance, management, manpower training, fuel subsidy, fuel processing subsidy, waste disposal, antitrust concessions, tax exemptions, accelerated depreciation, insurance subsidy and liability limitation, etc.)
  2. State taxpayers(2) (tax exempt bonds, foregone development, investment credits, monitoring and administrative costs, other tax breaks, etc.)
  3. Public health (worker safety, cancer, and other radiation-induced diseases, etc.)
  4. Environmental (agricultural and wildlands damage, animal kills, etc.)
  5. Private enterprise(3) (risk of plant failure and unreliability, sensitivity to price increases, cost of standby equipment and fuel, etc.)
  6. Personal freedom (police power infringement to protect plants, costs of dissenting citizens, etc.)
- C. Costs With Uncertain Incidence (disposal costs for wastes from American-built foreign reactors, military expense to balance new threats by foreign nuclear powers, police assistance to guard foreign nuclear industries from plutonium and other radioactive material thefts, etc.)

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(1) These are the costs to utility stockholders from bad investments, to utility management from bad decisions, to nuclear plant manufacturers who cannot recover expenses, etc. Since this category does not include expenses that are recovered from electricity sales (Category I), no double counting occurs when the four categories are summed.

(2) Government leasing policies, which reduce revenue from publicly owned energy sources, lower the ability to provide government services and/or increase the rates of taxation. Energy pricing structures do not distribute this sort of energy subsidy on a per capita basis.

(3) Including the costs of power shortages due to nuclear plant unreliability.

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ability of fuel; the operators choose an optimal fuel deterioration before refueling; the development of breeder technology is dependent on both availability and favorable price of reprocessed waste; and the rate of implementing any nuclear technology depends on the opportunity cost of each developmental sequence. To the extreme, a very high cost of radioactive waste disposal might make fossil-fuel systems a less expensive utility choice. The substitution of fossil-fuel units would be particularly evident in locations where they are already very competitive options. For a more thorough discussion of these relationships, see Andersen (Ref. 1).

As economists and risk analysts identify social costs that have been previously ignored by utility planners and incorporate those costs in electric rates, a healthy economic process ensues. Consumers react to the higher prices by increased insulation, improving appliance and machine efficiency, and through readjustment of their consumption priorities. These substitutions, among energy sources and between conservation and supply options, are the mechanisms that a free society uses to allocate resources.

Both the substitution of one energy source for another by the cost minimizing utility and the consumer decision to conserve energy are constructive economic changes prompted by the inclusion of a cost in the price. The cost of radioactive waste disposal is inherent in nuclear technology even if it is paid by taxpayers rather than by electricity users. Economists advocate the full inclusion of costs in the prices of products and services so customers can have accurate price signals to guide their spending decisions. It is uneconomic to sell electricity from nuclear plants at a subsidized price and to charge the incidental cost of waste disposal to citizens through taxes. If decisions to protect the public from radiation increase the cost of nuclear technology to the point that society will not buy the electricity, so be it.

The economic regulation of waste allows utilities and other radioactive waste generators to seek out whatever means achieve mandated safety assurance at least cost. If we assume that the disposal is not completely failsafe and that a positive element of risk (as a function of probability and consequences) remains, a two-part service charge is necessary to encourage economic efficiency. The first charge is set to recover the actual expense of building and operating the facility. The second surcharge is set equal to the expected health and property damage over the interval of waste storage. Because our estimates of release may not be correct, it is appropriate to require utility funded insurance to accumulate financial reserves sufficient to protect future generations against unacceptable expense of remedial actions. This two-part charge to the utility should be treated like any other cost of doing business.

The goals of efficient resource allocation are pursued by continual efforts to identify and incorporate neglected costs in decision calculations. For nuclear electric power plants, waste disposal costs are merely one element of the externalities. Table 1 presents an outline of these currently neglected expenses.

The process of increasing the price of nuclear technology to approach its real cost will encourage nuclear advocates to join with governmental agencies in constructive efforts to raise the price of alternative energy to reflect its full social costs. This process is a sharp contrast from current industry arguments to maintain subsidies via unaccounted environmental costs for all hazardous energy sources. Higher overall energy prices will dramatically encourage America's energy conservation goals.

ENGINEERING AND GEOLOGIC UNCERTAINTY IN SITE SELECTION

John Bartlett's paper (in these proceedings) offers an excellent overview of risk assessment in uncertain environments. I cannot improve upon his presentation but I would suggest several additional concerns:

1. Now that the resolution of radioactive waste storage is a major physical and legal barrier to expansion of the nuclear power plant industry, how can we isolate scientists from the substantial pressure to choose a "solution" prior to comprehensive investigations?
2. Given the limited geological mapping outside mineralized areas in the United States and other developed countries and the even more limited understanding of the remainder of the earth, how can we be sure that the first sites selected within our country are acceptable relative to the potential for safe storage?
3. If the earth's crust includes only a few acceptable sites for safe disposal, how will we allocate the limited capacity among those nations who elect to produce the waste? Is it judicious to signal a go-ahead to the nuclear industry after identifying a single tentative plan for disposal when substantial undisposed radioactive waste already exists?
4. How can current and unanticipated scientific discoveries of man's impact on geologic stability (such as the recent correlation of increased seismicity from reservoir foundation loading) be factored into site selection?

CONCLUSION

Economic regulation of radioactive waste disposal can guide the choice of sites, select the level of engineered protection, and provide the proper incentives for modification or rejection of the nuclear fuel cycle. Such regulation must specify the conditions of safe disposal and assign the program plus the storage hazard costs to the originators of new radioactive waste.

The choice of cost-effective disposal must be made independently of the financial impact on nuclear power plants. If that technology cannot pay its own way, society is better served by postponement of its use.

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ANALYZING THE DECISION ON RADIOACTIVE WASTE MANAGEMENT

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INTRODUCTION

Radiation waste management is not a problem that can be avoided by withdrawing the commitment to use fission reactors to produce electric power. The reactors already deployed and the military weapons program imply that society must now decide what to do with large quantitites of radioactive waste material. Further development of nuclear electric generation will add more to the quantity but the necessity for decision has already arrived.

Why is radiation waste management such a difficult area of public policy? There are several contributing factors. The waste is extremely toxic, and it retains its poisonous characteristics for a time period far longer than human institutions are thought to endure. It can be transmuted into an inert form only at great cost and difficulty. How can these poisons be contained for a long enough period, considering the multitude of potential future events that might cause the containment to be breeched? How can we be sure that for the next million years the monster will remain in its cage?

Radiation waste management therefore involves assessing the small probability of a potentially catastrophic event, for which the information available to base the assessment is scanty and complicated by the vagaries of human nature: human error or human malevolence might lead to release.

How can quantitative analysis possibly deal with such problems in a way adequate for public policy? It is an awesome task, and we could spend many years discussing all the aspects that make it so difficult. But in the meantime, we have already accumulated a great deal of radioactive waste, and we are committed to accumulate more. What are we going to do with it?

THE ROLE OF ANALYTICAL METHODOLOGY

The focus of our discussion becomes much clearer if we agree at the outset on a starting point: the United States and other industrialized countries face a decision on how to manage radioactive wastes. Whatever the methods, rational or irrational, quantitative or qualitative, the decision exists and society must deal with it. Postponement or pretending the

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decision is not there are possible alternatives, of course. If we wait for perfect decision criteria or for all of the analytical difficulties to be resolved, we choose the postponement alternative by default. Let us agree that the need for decision on radiation waste management exits, and that we want our decision makers to do the best job they can to confront this need and act in society's interest, consistent with the information that is available now or that can be made available in the immediate future.

The role of quantitative analysis is not to provide perfect cut-and-dried answers, but to try to help decision makers, experts, and concerned citizens in arriving at a decision. We cannot expect quantitative analysis to magically resolve our uncertainty about the evolution of technology, society, and human nature over the next million years. We can only use it as a framework for integrating the available information and judgment, and for pointing out where differences in judgment are most significant.

Critics of quantitative analysis are fond of stating that the problems are so complex and the available information so inadequate that "we do not know enough" to do a quantitative analysis. This viewpoint misses an understanding of what the role of analysis is, but this criticism has much justification. Most of us have seen calculations that summarize very complex issues into a "bottom line" number. Given that these calculations exist, there is a temptation to take that number out of context and treat it as "gospel." "The government had XYZ Research, Inc., do a risk analysis and the answer was six chances in a million." The analyst responsible for calculating that number may cringe as his carefully thought out caveats and assumptions are passed over in the rush to find that bottom line, which is then treated like a mysterious pronouncement from the Delphic Oracle. This is a mode of decision-making that has been common in complex technological matters: leave it to the specialists who understand the subtle technical issues involved. Unfortunately, this approach does not always prove satisfactory. The specialists are not without biases, their specialization may not be broad enough to encompass the full range of issues involved, and they often fall prey to the weakness of leaving out or glossing over those aspects of the problem that they do not understand very well.

Therefore, it is said, let us force these specialists to tell us how they arrived at their recommendations, and let us subject them to cross-examination and adversary proceedings against other specialists who hold differing views. What emerges from this process is also frequently unsatisfactory: Each side presents detailed arguments, scenarios, statistics, and examples in which some issues are examined ad nauseum and others are ignored. Laymen and public officials may be confused by the complex and conflicting testimony. The decision process may reduce to lengthy and inconclusive hearings in court, or popular referendums on which the opposing interest groups hire clever ad agencies to compete for the voter's attention, so as to resolve the issues on which the technical experts and political leaders cannot agree. The process is inefficient and frustrating, and many on both sides assert that the decisions are being arrived at for the wrong reasons. But it is a democratic process, and what better alternative process do we have?

Let us take another look at analysis, but as a framework for integrating the issues affecting a decision rather than as a formula for computing an answer--a bottom line. The role of the analysis should be in communicating the process--how to get to the bottom line, and how various judgments or items of information might affect it, and hence, affect the decision. If we do not perform any explicit calculations, the many complex factors bearing on the decision must be integrated another way, such as through the subjective judgment of specialists.

The role of the analysis is not to provide an answer, but rather to provide insight that will assist the political leadership, the technical experts, and concerned citizens in the process of reaching a decision. In other words, the analysis should never assume the responsibility of the decision. That responsibility should remain with the people who had it originally. Analysis is useful only if it helps those people to understand better the decision for which they have responsibility. As society confronts difficult decisions such as what to do with radioactive waste, there is a temptation to wish for an analysis that would make the decision obvious, and ease the burden of responsibility. Despite the enthusiasm of the analyst to assume responsibility and the tendency of some of our leaders to shun their responsibility by seizing the bottom line the analyst develops, the responsibility for social decisions must remain with the people and institutions that have been set up for the purpose--the electorate, elected officials, their appointees and advisees, and the courts.

ANALYSIS AS A FRAMEWORK FOR INTEGRATING THE ISSUES RELEVANT TO THE DECISION

The caveats mentioned above on the role of analysis should tell us that we should not be wasting our time debating whether all the important factors related to waste disposal and storage can be included in an analytical framework. Rather, let us assume we are setting out to do the best job we can to help decision makers discharge their responsibilities to deal with the radiation waste management problem. If the analyst is successful, the decision maker will feel he has been helped. To the extent that the analysis is unsuccessful in dealing with an issue, the decision maker is going to have to confront it anyway with whatever means are at his disposal.

Let us now turn our attention to the analytical tools and try to achieve a perspective on them. In order to address an issue like radioactive waste management, we need to have the means to model complex causal sequences, to deal with uncertainties, and to characterize the trade-offs among conflicting objectives that the decision may entail. Fortunately, there is a developing body of knowledge on how to apply analysis to personal, corporate, and social decisions involving uncertainty, complexity, and conflicting objectives. The approach is called decision analysis, and it has been applied to social decisions in weather modification, fire protection, pollution control, energy policy, electrical system capacity planning, and other areas (Refs. 1-8).

We will draw heavily on the concepts of decision analysis in the discussion that follows. We will first discuss the elements of the waste management decision and how they are related. We will then discuss the role of the various parties--technical experts, decision makers, and concerned citizens--involved in the decision. Finally, criteria for choosing among alternatives will be discussed.

Associated with every decision are alternatives, information, and preferences. A good decision, in a personal context, is one that is logically consistent with the decision maker's available alternatives, his state of information, and his preferences. Both information and preferences are subjective. The principal differences between social and personal decisions relate to the way information and preferences are incorporated in the process. The interested parties or shareholders in the same decision can have widely differing values (preferences), differing degrees of uncertainty, and even differing models of the way events are related. For example, some people are confident that if our wastes are buried at a reasonable depth in a salt bed, they will stay buried for at least the next 1,000 years. Furthermore, some people would be unwilling to pay even a few cents to avoid a premature death due to a reemergence of the waste in the year 2978. Other people might assign a high probability that experts are wrong and assess a much higher probability to early release or they might wish to assign a much higher value to the health of distant generations. But in spite of these differences or complications, let us examine the elements of the waste management decision and their interrelation. At a minimum we can use a decision analytic framework to organize and clarify the issues.

The decision structure is sketched in Figure 1. The alternatives include the processing, transportation, and the storage or disposal options. Associated with each alternative are the possible significant outcomes measured in appropriate terms. For the waste decision, the outcome measures are mortality and morbidity resulting from voluntary exposure, involuntary health risk, damage to biota, property damage, and the contribution of waste management to the cost of electricity. The outcome associated with each management alternative is uncertain because of geologic, economic, and social factors that are beyond our control. For the purposes of identification (classification), we call these influential but uncontrollable factors "state variables." They include such things as the timing and intensity of earthquakes, the economic value of any valuable elements that might be extracted from the waste, the location of future population concentrations, the size and timing of meteor impacts, and the size and timing of any human efforts to penetrate a waste disposal site.

INFORMATION AND JUDGMENT

Information and judgment enter the decision in two places: (1) in describing what is known about the relationship between decision, state, and outcome variables; and (2) in describing our knowledge or lack of knowledge about the values of the state variables. Our knowledge of radioactive decay processes, containment integrity, dispersion, population exposure, and health effects may be summarized in quantitative models. The accuracy of these models depends, of course, on the skill of the modeler, the knowledge of the experts involved, and the resources allocated to the modeling effort. In most cases such models can be improved and refined through critical adversary review.

If used properly, quantitative models can serve several important functions in a social decision. Firstly, they can be used to identify those state variables and model elements that significantly influence the decision. Public review can then be focused on the issues that matter. Second, the model organizes the information in a concrete form so that it can be constructively reviewed by all interested parties. Specific areas of disagreement can be identified and the implications of disagreements can be measured.

Even if we had perfect models, outcomes associated with each decision alternative would still be questionable because of uncertainty in the state variables. No amount of experimenting or analysis can remove all this uncertainty. The best we can do is describe probabilistically what we know about these quantities or events and make a decision that is consistent with this judgment.

In the social decision context, the question arises, "Whose information or knowledge do we use?" In many cases the probability distributions describing the uncertainty cannot be estimated experimentally, and therefore we rely on purely subjective assessments. For instance, what is the probability that a cure for radiation-induced cancer will be discovered before the year 2100? There is no known way of resolving subjective differences among experts. If the difference of opinion has an impact on the choice among waste management

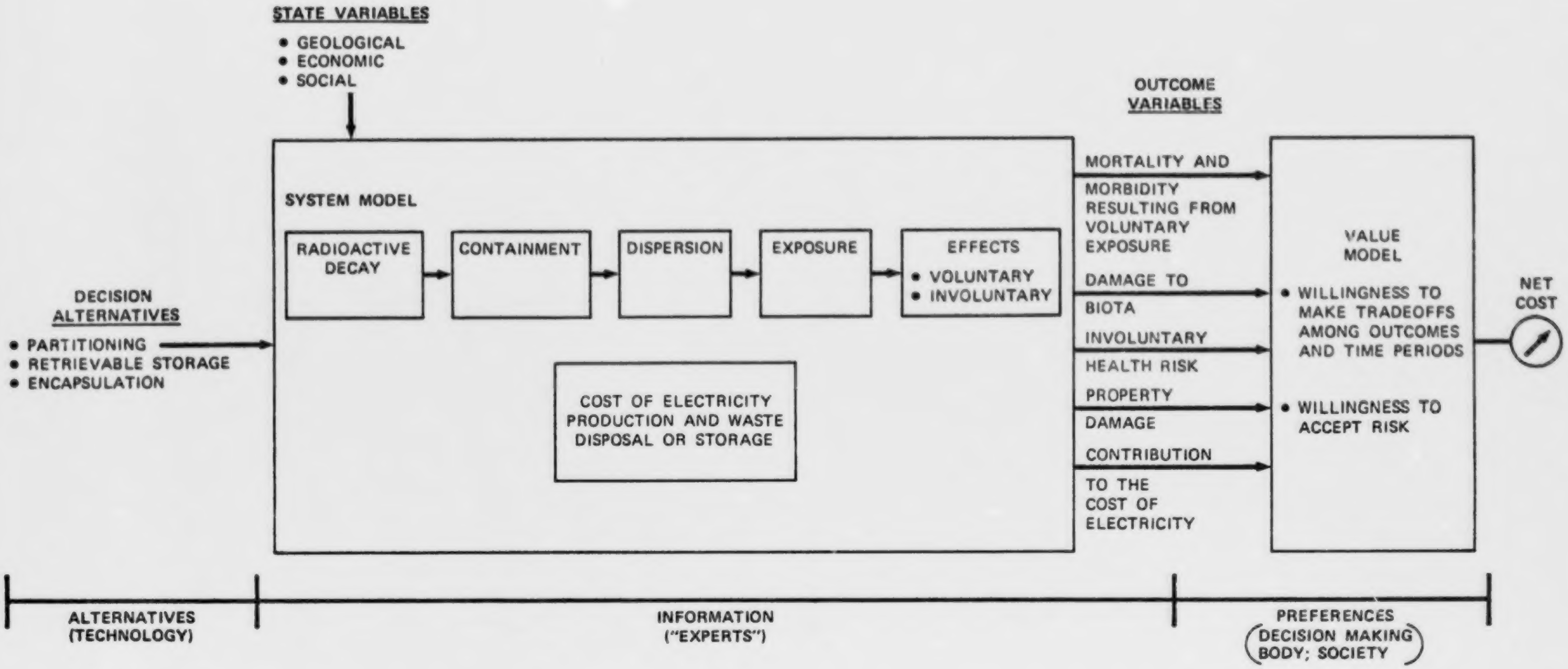
STATE VARIABLES
• GEOLOGICAL
• ECONOMIC
• SOCIAL
DECISION ALTERNATIVES
• PARTITIONING
• RETRIEVABLE STORAGE
• ENCAPSULATION
SYSTEM MODEL
RADIOACTIVE DECAY
CONTAINMENT
DISPERSION
EXPOSURE
EFFECTS
• VOLUNTARY
• INVOLUNTARY
COST OF ELECTRICITY PRODUCTION AND WASTE DISPOSAL OR STORAGE
OUTCOME VARIABLES
MORTALITY AND MORBIDITY RESULTING FROM VOLUNTARY EXPOSURE
DAMAGE TO BIOTA
INVOLUNTARY HEALTH RISK
PROPERTY DAMAGE
CONTRIBUTION TO THE COST OF ELECTRICITY
VALUE MODEL
• WILLINGNESS TO MAKE TRADEOFFS AMONG OUTCOMES AND TIME PERIODS
• WILLINGNESS TO ACCEPT RISK
NET COST
ALTERNATIVES (TECHNOLOGY)
INFORMATION ("EXPERTS")
PREFERENCES (DECISION MAKING BODY; SOCIETY)

Figure 1. Anatomy of a decision.

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alternatives, then the decision maker or decision-making body must ultimately pick the source of information upon which to base the decision. Differences of opinion can be judiciously ignored if they do not affect the best choice among alternatives. One cannot help but wonder how many hotly debated issues could be defused if we had a logically consistent framework for testing their importance in the decision at hand.

PREFERENCES

The outcome of any waste management decision is measured in several dimensions, it is distributed over a long time span, and it is uncertain. The "value model" on the right-hand side of Figure 1 includes an explicit expression of the decision-making body's willingness to make trade-offs between outcome measures. For example, how much are we, as a society, willing to increase the cost of electricity to avoid exposing a person living near a storage site to one chance in 10 million of contracting cancer induced by the waste? It is also necessary to express society's willingness to trade outcomes between time periods. Usually this is treated by choosing a reasonable discount rate. This may be inappropriate in the case of extremely long-lived hazards. Society might be willing to pay a great deal today to avoid jeopardizing the well-being of societies existing in the far distant future. This poses no conceptual difficulty. The value model is simply a statement of the weights to be assigned to the outcomes for purposes of making the decision. However, these values should be consistent with the trade-offs society is willing to make in other decisions. It is certainly possible, for instance, that the use of fossil fuels by present generations will also jeopardize future generations. In these decisions, appropriately or not, a simple discount rate is used to weigh future outcomes.

Few people would be naive enough to assume that specifying values to be used for decision-making is a simple, straightforward orward It could well require all the legislative processes associated with routine law making. In other cases it could require the soul searching of a politically appointed decision maker performing his administrative duties.

In a well-organized decision-making framework, such as that represented in Figure 1, many value differences or conflicts may be avoided by demonstrating that the rational choice is the same regardless of one's position on a particular value assessment. Explicit expression of the trade-offs together with a system model can focus the effort on those differences that matter.

It should be noted that mortality and morbidity outcomes are separated into two categories: (1) mortality and morbidity attributed to voluntary exposure, and (2) risk associated with involuntary exposure. The first is measured in terms of the number of actual premature deaths or harmful health effects.

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The second is different; it can be measured as a total number of persons involuntarily exposed to the particular risk (probability of effect). The social value of the bad outcome from voluntary exposure might well be thought about in terms of lost productivity or families without bread winnners. The second, however, is more subtle. It is related to the compensation that each of us could require to induce us to voluntarily participate in a risk situation that we would ordinarily try to avoid.

DECISION CRITERIA AND RISK ATTITUDE

The decision criteria become especially difficult to formulate when the consequences of the decision include catastrophic outcomes. How do we make the trade-off between a slight increase in the probability of catastrophe and a modest but still significant saving in cost?

The simplest approach is to use expected value as a criterion, with a monetary equivalent assigned to the catastrophe. This approach has become widely accepted in some areas such as transportation safety planning, and values of life such as \$200,000 to \$500,000 are used (Ref. 9). More sophisticated calculations may employ von Neumann-Morgenstern utility (Refs. 10, 11) to include the effect of risk aversion, but this approach does not address the most difficult issue--how to assign value to the catastrophe. Hirshleifer (Ref. 11) and Howard (Ref. 12) have pointed out the need to directly address the trade-off between increments of probability of the catastrophic outcome and a decision maker's willingness to pay (or accept payment). This trade-off can then be used to establish a value to the catastrophe for decision-making purposes valid for small probabilities. For example, the judgment that society would be willing to pay \$10 million per reactor year to reduce the chance of a nuclear reactor accident from 2×10^{-6} to 1×10^{-6} implies a value of $\$10^7/(2-1) \times 10^{-6} = \$10^{13}$ assigned to the accident, for calculations with probabilities in the range of a few chances in a million. But this judgment should not be taken to imply that society would tolerate reactor or ident probabilities in the range of 1 to 10 percent, even if trillions of dollars in economic gain could be realized. A model for assessing the probability of death versus willingness to pay trade-off will be described in a forthcoming paper by Howard (Ref. 13). Howard's approach incorporates both time preference (preferred distribution of consumption) and a von Neumann-Morgenstern utility function.

Despite the difficulty of the assessment, a formulation in terms of a trade-off between the probability of catastrophe and the economic cost (or willingness to pay) associated with each decision alternative seems to be useful and appropriate. This approach has been used not only in safety applications involving the value of life, but also in space exploration where biological contamination of planets is the low probability catastrophe to be avoided (Ref. 14).

The alternative to using an explicit assessment of the trade-off between economic gain and probability of catastrophe are criteria such as best practical technology, or probability constraints that must be met irrespective of economics. The weakness of probability constraints is that they give no incentive to reduce a probability below the constraint threshold, and they may induce a negative value to information that could show the constraint to be violated. As a hypothetical example, one might "rather not know" whether the chance of water penetrating the salt dome in the next million years is one in 10 million, or one in 10 thousand, if in the latter case the constraint would be violated. Without the information the probability might be one in a million--above the constraint. Examples and further discussion of the weaknesses of a constraint formulation are found in a report by Howard et al. (Ref. 14).

Qualifiers such as "low as practical," "safe enough," and "adequate safety" avoid the difficulty of assessing the trade-off, but besides suffering from ambiguity, they suffer from the same problems as probability constraints. Unless some balance is struck between the probability of release and the economics of waste management, a negative incentive exists for the development of new technologies for waste storage and disposal, and for obtaining more information about the effectiveness of the approaches to guaranteeing containment. Any new technology that appears safer may be mandated, regardless of cost or side effects; any new information showing that a technology is less safe than previously supposed causes widespread alarm and perhaps costly rejection of that technology. Explicit trade-offs may be difficult to establish, but they provide the reference point to keep the decision process from being whipsawed by every new bit of information that is developed.

A PERSPECTIVE ON WASTE MANAGEMENT CRITERIA

We shall conclude with a short personal perspective on the problem of developing criteria for radiation waste management. We will direct our remarks primarily at high-level waste instead of lower-level waste, where routine emissions may be more of a problem. For high-level wastes the problem is primarily one of containment--making sure that the probability of catastrophic release is acceptably low.

Observation 1: Assessing the probability of release is a difficult job that will never be entirely finished. Ongoing modeling is needed to assess the probability of release and insure that all cost-effective means of lowering this probability will be employed. The modeling exercise itself may be highly subjective, particularly in those areas where our understanding of the release mechanisms is weakest, e.g., the deliberate actions of governments or individuals. A good decision is one that is logically consistent with the information available to the decision maker. In many cases the best information available to us is the informed subjective judgment of experts. As new information is obtained, the models and probability assessments should be revised accordingly.

Observation 2: The consequences of possible releases should be assessed, and used as guidelines to bound the losses for probability versus cost trade-off assessment. Is it true, for example, that a major release caused by a direct meteor impact at a waste burial site would be no worse than the cumulative effects from atmospheric weapons testing? (Ref. 15). What are we willing to pay to reduce the probability of this outcome from 2×10^{-13} to 1×10^{-13} per year?

Observation 3: Is there a potential consensus? If indeed we can agree that for some waste storage technologies the probability of release is small (1 chance in 10^8 or 10^9), the consequences of release are less than infinite (we do not destroy life on earth or even over a substantial region), so the present value of the catastrophe is agreed to be of the order of a trillion dollars or less (in the context of 1×10^{-8} level probabilities), and if the cost of the storage/disposal alternatives is moderate (the order of one billion dollars or less), then it may be that we have a relatively straightforward decision situation. The potential consensus is that various waste disposal or storage technologies are acceptable. If more quantitative analysis can help to show that such a consensus is possible, then let us get on with this analysis. Hopefully this will help decision makers to end their indecision and to clarify the radioactive waste storage/disposal question in the larger social decision on the future role of nuclear power generation.

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REMARKS FOR THE EPA WORKSHOP ON ENVIRONMENTAL PROTECTION CRITERIA FOR RADIOACTIVE WASTES

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These informal comments are directed to the use of risk assessment in the process of setting generally applicable environmental radiation standards for radioactive waste management. My comments presume that risk assessment will have a role in the process; they are addressed to what that role might be. The comments are allocated to three topical areas: viability of risk assessment for these purposes, risk tradeoffs, and risk assessment in the public arena.

VIABILITY OF RISK ASSESSMENT IN RADIOACTIVE WASTE MANAGEMENT

You have previously heard that risk assessment methods have been developed for and applied to some waste management operations. Are these methods necessary; are they sufficient; and in particular, do the results provide a firm base for decisions and environmental protection criteria?

Let me first state (without necessarily endorsing) the viewpoint that risk assessment serves to quantify and confirm what we already know. The "already know" part of this assertion comes from the fact that we usually have, through experience, reliability data on performance of system components. What risk analysis does is quantify expected performance of a particular system of components. Implicitly, then, risk assessment requires explicit system designs, site, conditions, and scenarios in order to quantify probabilities and consequences of accidents and system failures.

At present, radioactive waste management seems to be lacking the system elements needed to produce viable results from risk analysis. Sites for waste management operations have not been selected, and specific designs for waste management systems have not been developed. I believe, however, that these deficiencies are temporary. As soon as sites are selected and system designs are promulgated, it will be possible to perform conventional risk analyses for all waste management operations with the exception of geologic isolation, which I will discuss later. Results of such analyses can serve their usual role of supporting licensing and environmental impact statement needs.

In the meantime, how can risk assessment help meet the needs of the (EPA) Environmental Protection Agency? One can assume a generic or reference environment. But the important things with respect to setting and meeting generally applicable environmental radiation standards are the inputs and outputs of radioactive materials and the extent to which they put the inhabitants of that environment at risk. On a nuclide-by-nuclide basis, the key element of risk is the interaction of inhabitants with radioactivity in the environment; allowable levels of radioactivity in the environment will depend on the mechanisms and extent of interactions.

It seems to me, therefore, that a key role for risk assessment with respect to EPA's needs is to derive allowable environmental standards on the basis of "acceptable levels of risk" (a topic I won't presume to address) and the mechanisms of interaction that can produce risk. The concepts of risk assessment can be applied to a system wherein the radioactivity in the environment is the source term and the biosphere pathways constitute the system elements for which fault trees and the like can be derived and evaluated. Currently available models for estimating radiation dose are, in essence, risk analysis models. The problems for EPA are related to setting the allowable dose (i.e., risk), validating the models, and working backward through the models to derive the source term.

After a generally applicable environmental standard has been set, the requirement for waste management operations is to constrain releases so that allowable limits are not exceeded. This means, in general, that inputs from waste management operations to the environment must balance outputs so that steady-state concentrations are at or below the standard. One output from the environment is radioactive decay, which, for the long-lived nuclides, is negligible for the risk period of a given population. Are there other outputs, in the form of immobilization mechanisms, that render some fraction of the radioactivity inventory insignificant as a source of risk? Such outputs will have to be defined and evaluated in order to set performance requirements for the waste management operations.

The waste management operation of key concern is geologic isolation. Can isolation be maintained for as long as necessary? Does risk assessment have a role in determining capability to maintain isolation? How can we deal with the fact that loss of isolation or change of repository configuration does not necessarily produce risk to population?

Conventional risk analysis methods may have a role in evaluating long-term safety for geologic repositories. For example, they can be, and have been used to generate and evaluate geologic fault trees. However, such methods deal only with mechanisms and probabilities of loss of repository integrity. They also are limited in their scope; other probability-oriented scenarios must be dealt with, such as human intrusion.

In general, the problems associated with attempting to apply risk analysis to long-term repository safety are these:

1. The scenarios for risk tend to be unbounded
2. Error bands on consequence analyses are extremely broad
3. Probabilities of geologic change tend to integrate to unity
4. Results cannot be verified.

There have been no complete (probabilities and consequences) long-term risk assessments, for geologic repositories. Typical scenarios have been investigated, but the spectrum has not been fully defined and evaluated. At present, the prognosis is that conventional methods might be used, but error bands on results will be very large. Supplementary and refined methods (e.g., probability density functions) may be needed. In any event, validation and acceptance of results of risk assessments for long-term safety of geologic repositories will be a difficult and challenging task.

RISK TRADE-OFFS

This portion of my remarks deals with the question, who's at risk, and how does it matter? Waste management options produce opportunities to trade or shift risks from one portion of the population to another, and from one generation to another. Assuming the existence of radioactivity is immutable and a measure of (at least) risk potential, how should potential risks be allocated?

Fundamentally, options for waste management technologies provide options for discharging radioactive or other effluents to the environs or containing the wastes for isolation from the biosphere. The ultimate containment or isolation concept is geologic isolation, which raises issues of export of risk to future generations. Note that if geologic isolation is successful and practiced to the limit, radioactivity-related risks to present populations are confined to occupational exposure and accidents, and such risks to future populations are limited to those associated with intrusion scenarios.

The problem of risk trade-offs, is rather subtle and involves cost-benefit considerations. In general, preparation of wastes for geologic isolation requires a waste treatment operation to change the form of the waste to one suitable for transport and isolation. The treatment process will usually generate effluents and proliferate waste forms. For example, combustion of process trash will generate gaseous effluents. Such effluents would be rendered essentially nonradioactive by installing HEPA filters; the HEPA filters become a waste form not present if simple compaction is used as the treatment operation. The effluents, although nonradioactive, contribute (however imperceptibly) to carbon dioxide discharges to the atmosphere.

Another example of a waste type that provides trade-off issues is krypton-85. If this gas is released to the environment, no capital and operating costs for capture and other waste management operations are incurred. If the krypton is captured, such costs are incurred, occupational exposure is increased, and with present technology, a concentrated source of radioactivity contained in high-pressure gas cylinders is created and subject to accidents during transportation, storage, and handling. Furthermore, the processing equipment becomes a waste to be disposed of when the facility is decommissioned.

In my opinion, the optimum distribution of risk as reflected by isolation philosophy, discharges to the environment, and environmental standards is not at all obvious. Comprehensive cost-risk-benefit methods for determining an optimum seem to be required. However, a further problem exists, which I have previously termed "beneficiary bias." You can always get the answer you want with regard to the consequences of a waste management action that changes the at-risk population element, depending on which group (increased risk or decreased risk) you side with. In sum, this is another problem for which obtaining a consensus will be a difficult and challenging task.

RISK ASSESSMENT IN THE PUBLIC ARENA

Risk assessment as a means of evaluating potential impacts of technology on society is a relatively new art; impacts of technology on society are old hat. Where and how can risk assessment actually affect decisions and standards that anticipate potential adverse effects of technology?. In other words, how much weight can and should risk assessment have?

In a first-order attempt to answer this question, I reviewed qualitatively past societal experience with major impact technologies. In my own mind, the only consistency I found was inconsistency.

In the past, without risk assessment and an Office of Technology Assessment, we seemed to always misestimate the impacts of technology on society. We therefore tended to misset the standards that reflect control of the technology to the benefit of society. Consider, for example, this table relating projections to impacts on society:

	"Bads"	"Goods"
Overproject	SST? WASH-740?	Rocket travel
Underproject	Thalidomide	Auto and air travel Microelectronics Computers

It is difficult to find entries for such a table in the overprojection-of-bad-impacts category because such technologies never even get started. For those that do, we usually find some need to revise and accommodate the unexpected. But our approach to revision and accommodation is also apparently inconsistent. For example:

1. Continued despite disaster (Titanic): luxury liner sea travel
2. Terminated by disaster (Hindenberg): commercial dirigible travel
3. Revised by disaster: earthquake design of structures, design codes for steam engine systems
4. Revised (introduced) by perceived potential disaster: automobile exhaust emissions.

On this basis, there appears to be some sort of subconscious risk-benefit evaluative system that affects society's use of technology. Is it consistent? Can it be quantified sufficiently so that "proper" values of environmental standards for radioactive waste management can be established? To investigate and answer such questions would require a multi-disciplinary study of major proportions.

One possible way to use risk assessment in this context is to take a "bound-the-problem" approach. This could require two types of effort: one to evaluate the magnitudes of our past underestimates of technology's impacts, and the other to estimate comprehensively an upper bound of potential impacts and risks of waste management options on the basis of known information. We might then show the consequences of present-day underestimation of potential risks: if waste management risk estimates extended by worst-case underestimates for past technologies still fall below "acceptable" levels, we could conclude that our technology is "safe."

In broadest terms, our current problem is to determine if and how the illusions of certainty created by the analytic methods of risk assessment can be accommodated in a society that distrusts computers and perceives risk subjectively. For this problem especially, there are no easy answers.

RISK CONSIDERATION OF RADIOACTIVE WASTE MANAGEMENT: SUMMARY AND CONCLUSIONS OF WORKING GROUP 2

RISK CONSIDERATION OF RADIOACTIVE WASTE MANAGEMENT

The function of Working Group 2 was to determine how risk considerations should come into play in the setting of criteria and standards for radioactive waste management. The nine-member panel was composed largely of professional decision analysts, engineers, and economists. The working group itself, numbering about 20, was composed of government employees and consultants, with some representation from academia and public interest groups.

The Working Group initially selected the issues that should be discussed. One immediate concern was the definition of important terms, such as "standard," "criteria," and "risk methodology." Although no consensus developed concerning precise definitions for these terms, there was agreement on the general proposition that "criteria" were rules that should be used in establishing a "standard" and that standards should probably be numerical in nature. Throughout the discussion, the group agreed that the ultimate goal was to incorporate risk analysis into the process of setting generally applicable standards for nuclear waste management.

The questions and topics addressed by the group were for the most part those posed on pages 2-7 and 2-8 of the document "Issues and Objectives Statements," distributed at the commencement of this Workshop. Of these 10 questions, numbers 1 through 9, or slight modifications of them, were discussed. Because of time considerations, number 10 was omitted. Prior to the conclusion of the session, however, one additional question was treated.

In the ensuing discussion, the questions, as formulated by the group, are presented, followed by the range of opinions expressed and the extent to which a consensus (if any) was reached.

1. Should the probabilities and/or consequences of abnormal or unplanned events associated with radioactive waste management plans be considered in the development of criteria and standards? If so, in what manner?

Group discussion and a paper presented by Dr. Bartlett explored this issue. Quantification of risk under operational and accidental situations is possible; however, the technique for incorporation of low-probability, high-consequence risks in criteria is problematical. Nevertheless, there was a clear consensus that environmental criteria and standards, and in particular the high-level and transuranic wastes standards, should address unplanned or accidental events. It was noted

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that such an accident standard would differ from the EPA radiation standards for the uranium fuel cycle. A related view also held that if accidents and unplanned events are to be included for high-level waste criteria and standards, then the intent must be to make a general practice of this for all radioactive wastes and for all EPA radiation criteria and standards.

Discussion focused on how low-probability, high-consequence events, whether natural catastrophes or accidents, can be considered. It was generally agreed that risk was a function of probability and consequence, but expression as a simple product, i.e., Risk = Probability X Consequence, may not be applicable. As a supplement, explicit discussion of probability and consequence was deemed desirable. Maximum credible accident approaches and Delphi analysis were considered to be inappropriate methodologies in comparison to fault tree, event tree, and consequence analysis techniques.

2. Should quantitative risk analysis be attempted in support of environmental criteria and standards?

The discussion centered on the topic of high-level waste disposal. There was clear consensus that quantitative risk analysis should be attempted to the extent possible, but that it should be regarded as an imperfect tool. It can, however, at least be used to indicate direction and magnitude.

It was recognized that assembling actual data for such analyses would be an extremely complex and, in some cases, an impossible task. For cases where data cannot be obtained (e.g., longevity of geologic stability), it was agreed that solicitation of opinions and projections from a wide range of knowledgable persons (e.g., a Delphi technique) must be used.

Opinion on the range of disposal techniques (e.g., geologic, extraterrestrial, transmutation) that needed to be analyzed was varied. Several participants believed that more options than geologic disposal needed in-depth risk analysis. A consensus evolved that geologic isolation should receive priority for analysis, with other options being considered to the extent that information is available.

Some discussion focused on factors that can diminish effective use of risk assessment. One item mentioned was the enforcement difficulty inherent in failing to consider variability of background, a fact that supports the concept of a locally oriented standard. However, it was pointed out that we do not know the health effects of background levels.

Another question raised was whether to treat the population as a whole or to segment it. If it is to be segmented, should this be done on an occupational or nonoccupational exposure basis, or some other basis? This question was not pursued or resolved.

Quantitative risk assessment methods should be used for categories of radioactive waste other than high-level. It was recognized, however, that techniques and requirements might differ according to the type of waste considered.

It was the consensus of the group that quantitative risk analysis should be prepared to support criteria and standards for all radioactive waste management plans. For high-level waste, emphasis must be placed on geologic disposal, but all viable alternatives should be analyzed to the extent feasible. All such risk analyses should be recognized as an imperfect tool to aid decision-making.

3. What analytical methods should be applied to various phases associated with waste management, such as transportation, repository operations, retrievable storage, and ultimate long-term disposal?

A possible method for performing quantitative analysis of risk was outlined for the above operations. This approach would consist of identifying initiating events of concern with fault trees and analyzing consequences with event trees.

Comments from the Working Group indicated that this, or similar approaches, may be applicable to short-term operational steps such as transportation and repository operations. Members of the group also pointed out that many risk/safety studies have been performed for transportation and that applicable models exist. The suggestion was made that in performing an evaluation of transportation, use of actual experimental data may be feasible. A point was made that general risk assessment models can be developed. These general models can vary the choice of logic structure and input parameters.

It was indicated that it may be difficult to apply existing risk assessment models to geologic isolation. One suggested approach is to identify a spectrum of events for consideration by consensus opinion or other means. Having generated this list, the probabilities and consequences can be estimated by the best means available.

While no real consensus was achieved, no major objections were raised to any of the points in the above discussion.

4. Given that appropriate methods have been selected, what data should be considered in quantifying the probabilities and consequences of abnormal or unplanned events?

No objection was raised to the suggestion that appropriate programs sponsored by ERDA and NRC be relied upon as the primary data source for the risk analysis. The following paragraphs briefly review the data requirements and availability.

The potential causes of breaching the containment of a nuclear waste repository in a geologic medium can be divided into two classes, man-made and natural. In the case of a man-made breach, data will be required on breach probabilities such as intrusion by intentional or unintentional drilling or mining through the disposal horizon by future generations. Estimation of these probabilities seem to be generally within current capability and are partially site-dependent.

The natural events capable of breaching the formation can be sudden and catastrophic incidents or gradual geologic processes such as erosion and successive vertical displacement by tectonic activity. The geologic data on catastrophic events, such as the impact of giant meteorites, of both the stoney and metallic type, are available but need a determination as to the "best values." The other potentially serious breach, large faulting, can be approached from both a deterministic and probabilistic viewpoint. General data on faulting are available, but site-specific data are required in the selected geologic basin or region. A thorough understanding of the site area is required. From this information, erosion and denudation characteristics of the region and the effects of large and successive faulting can be estimated.

Estimation of leakage from the disposal region resulting from water intrusion requires data on leaching rates of the waste for water or brine that is characteristic of the region. Further information is required on the absorption characteristics and flow through the geologic medium in order to evaluate transport through the geosphere.

The risk to the populace can be estimated at any time for a particular type and quantity of waste located at the disposal horizon by incorporating these data into a suitable model.

The foregoing discussion refers to the disposal phase--that is, after the repository has been back-filled and sealed. The operational phase is similar to the operation of a chemical processing plant from a safety analysis standpoint, and sufficient information for the specific equipment involved is available or can be obtained in a relatively short time.

Intrusion of the repository by man at some time in the future seemed to be of great concern. Consequently, additional effort should be made to respond to this concern by fortifying existing data to assess this risk.

5. What consequences are of concern in the risk assessment? For example, should the analysis be restricted to health effects of the types considered in the Reactor Safety Study? Or should questions such as the risks of compromising future resources of valuable minerals be considered?

There was a general consensus that the potential health effects to present and future generations constitute the most important consequences of concern in the risk assessment. However, the analysis should not be restricted to health effects, nor was the analysis so restricted in the Reactor Safety Study (RSS). The RSS considered the economic costs associated with property damage, which should also be considered in any risk assessment associated with radioactive waste management. Additionally, consideration should be given to the value of contamination of land, the loss of ecological species, the economic loss to the area associated with industrial output and employment, and the loss of natural resources (including minerals and water resources). Many of these attributes may not be expressible in monetary or commensurate units, but an effort should be made to provide estimates of these consequences in whatever units are appropriate.

The issue of international implications from the potential release of wastes to the oceans was also raised. Although there was some disagreement as to the nature of these implications and the responsibilities of EPA relative to them, it was generally agreed that this is an issue worthy of some consideration. Likewise, the ambient radiation levels arising from foreign nuclear activities should also be considered in the ultimate development of environmental protection criteria.

6. Can one reasonably predict through the time frame of interest what resources might be considered valuable? Can one assess the possibility of radioactive releases being caused by penetration of a repository by persons pursuing mineral resources?

Some members felt that the resources which will be valued in the future could be reasonably predicted. Others disagreed. The predictions of future mineral value can be attempted by substitution analysis presently used by the Department of the Interior, by data on existing mineral deposits, and by consideration of the cost effectiveness of removal of these minerals. Site selection presently considers the mineral content of the area under investigation (e.g., an area with present mineral value would not be considered). It was suggested that the site chosen should be a low-risk and low mineral content area. Sites with low projected mineral value would presumably have low probability of intrusion by mining operations of future generations. In light of this opinion, the second part of Question 6 was not further developed.

It was recognized that although the above discussion sounded reasonable, there is no guarantee that the projections would be accurate. General consensus about the ability to accurately predict future mineral value was not obtained.

7. How should the acceptability of the risks associated with radioactive waste management be determined?

This question was generally construed to concern the translation of waste-related risk assessments into a framework that would provide understanding to the decision makers and the general public in the establishment of criteria and standards. In this context there was agreement that acceptability has to be determined by decision makers and/or the public. Some questions were raised as to what was meant by "decision maker," but the consensus appeared to be that the decision maker was the Administrator of EPA (with broad input and subject to public acceptance).

Discussion concentrated around the comparison of waste management risks with other risks. It was agreed that such other risks should be involuntary, and recommended that several relatively comparable risks be used to provide illumination. Candidates for these included (1) commonly understood risks, (2) fossil-fuel risks, (3) balance of the nuclear fuel cycle, (4) direct impact of geologic events, (5) natural background levels, and (6) other waste sources. Subsequent discussions focused on the first two, and in particular on coal-to-nuclear fuel cycle comparisons. There was disagreement over the value of comparing nuclear to fossil, both for wastes alone and the entire fuel cycle. It was agreed that such comparisons should not be used as the basis for setting standards, per se; but there did not appear to be a consensus on the question of using nuclear/fossil comparisons even for illumination of waste disposal risks using current assessments. Comparison with commonly accepted risks seemed to be a generally approved method for aiding the determination of acceptable risk. However, several speakers cautioned against a trap of suggesting that risks lower than those of commonly understood occurrences implied acceptability. The question of present wastes versus those that might be generated in the future was again raised. Discussion focused on the use of cost-benefit ratios as cost per unit reduction in consequences, and the relative cost of reduction from one source to another, but it was not agreed that either of these increased the level of understanding of the issue.

There was consensus that risk assessment has to be presented in a framework which provided the best possible understanding of radioactive disposal risks to decision-makers and the public in order to determine acceptability. There was also consensus that this required comparison to other relevant and comparable risks, but that this comparison was not the only basis for decisions. There was no consensus on what the comparable risks should be.

8. How should future risks be compared with present risks?

The majority of the working group participants agreed that the concept of "discount rate" from financial calculations is inappropriate for intergenerational comparison of health and property risk. In the absence of a better role, the group generally agreed that all benefits and costs should be treated equally regardless of incidence. The group assumed that waste disposal systems will be designed to provide roughly equivalent minimal levels of risk throughout the toxic life of the waste, and that sites will be selected to minimize the value of foregone economic activity around the site.

It was also argued that if the technological and resource legacy passed on to future populations because of increased reliance on nuclear power plants were more valuable than obligations ions isks of waste storage, a lesser value of future life was valid. Alternately, it was suggested that the benefits of nuclear activities largely accrue to current generations, while only costs and risks accrue to future populations. This belief would support the selection of a disposal technology which shifts the bulk of cost and risk to the current citizens. Successful disposal in outer space might serve this goal. The variation of estimated risks could be calculated by sensitivity analysis using alternate values of life in each time interval.

9. How should risks from low-probability, high-consequence events be valued in comparison to the risks from high-probability, low-consequence events?

Since this question was raised late in the session, discussion was limited. One opinion expressed was that the direct impact might be much greater than the radiological impact for low-probability, high-consequence events asssociated with geologic storage or disposal. For example, the damage caused by vulcanism or a meteorite impact might far outweigh the loss of life or health effects from radiation release initiated by these events. For purposes of evaluating radwaste management strategies, the important aspects would be the difference in radiation release (and other effects) given different waste management strategies. For example, deeper disposal might lead to less release of radiation, even if the damage caused by this radiation would be small compared to the direct damage caused by the meteorite impact or volcanic eruption.

A note of caution was raised that in comparing low-probability, high-consequence events and high-probability, low-consequence events, a simple expected value criterion of multiplying the probability times a value assigned to the consequence may not be adequate. This problem becomes particularly acute if significant probabilities are associated with high-consequence or catastrophic events. For example, for probabilities in the range of 10^{-6} to 10^{-4}, it may be appropriate for decisions on highway safety to use a value for loss of life on the order of $300,000. On the other hand, for a decision on medical treatment, where the probability of death is in the range of 10^{-2} to 10^{-1} it might not be appropriate to use this value. A recommended procedure is to compare different decision alternatives directly in terms of (1) the effect in changing the probability, and (2) the effect on the magnitude of the consequence for both the low-probability, high-consequence events and the high-probability, low-consequence events. References on assessing low-probability, high-consequence events (such as loss of life) include Hirshleifer (Ref. 1) and a forthcoming paper by Howard (Ref. 2). There was general consensus on the need for caution in comparing by means of a single numerical index the low-probability, high-consequence events and the high-probability, low-consequence events in a quantitative risk assessment; however, within appropriate ranges such comparisons can be very useful.

10. How should the risks from various radioactive wastes be considered? (By waste type? By source of waste? Should they be ranked?)

Numerous and diverse opinions characterized the response to this question. Some questioned whether EPA should be issuing such criteria and standards in the first place. One position was that a single standard, regardless of waste type, is appropriate ("a rem is a rem is a rem"), but economic and technical realities dictate that control of dose per dollar invested is highly variable and that a variety of criteria and standards are probably more appropriate. Priority should be given to commercial high-level waste, but ultimate inclusion of all waste sources using a uniform approach is recommended.

Priority of control should be established according to consequence or risk and the potential for routine and accidental releases. An alternative approach suggested was to define an acceptable level of radiation in the environment and to design for releases not to exceed the standard. This touches on the distinctions between performance standards and specification standards or between ambient standards and effluent standards. The EPA role would seem to be clearly oriented toward the former, whereas ERDA and NRC criteria are performance-oriented on site- and/or process-specific bases.

Not all risks are equal in perception, in acceptance, and as input for decision-making at technical and political levels. It was recommended that EPA actively cooperate with other Federal agencies to develop the criteria and standards relating to commercial-fuel-cycle- and ERDA-generated wastes and that EPA not act in a vacuum.

Multiple approaches to criteria and standards development now in use such as risk-benefit, ALARA, and environmental dose commitment are not inappropriate nor are they fully adequate. The subject of imponderables, which surfaced frequently, underscored the consensus that such philosophical approaches are only a partial guide. Despite much debate there was no consensus that rigorous comparison of risk within the full fuel cycle (vs. only waste management) and between fuel cycles would be possible or productive with respect to developing criteria and standards. It was suggested that study of comparative risks of nuclear and nonnuclear would perhaps give a better perspective on the waste management issue. The methodologies of benefit-cost, benefit-risk, fault tree, event tree, and consequence analysis provide guidance but not necessarily precision with respect to waste management decisions. This, plus the fact that waste management has associated with it future risk uncertainties suggests that other considerations and measures are appropriate for evaluating and reducing risks associated with permanent, long-term disposal.

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WORKING GROUP 2 EXECUTIVE COMMITTEE

RISK CONSIDERATIONS OF RADIOACTIVE WASTE MANAGEMENT

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† Panelists for Plenary Workshop Session, 5 February, 1977.

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RESPONSE OF WORKSHOP PARTICIPANTS TO SUMMARY AND CONCLUSIONS OF WORKING GROUP 2

Second Plenary Workshop Session

JAMES E. MARTIN: (Environmental Protection Agency, Washington D.C.): I would like to introduce Tom McGarity from the Environmental Protection Agency in Washington, D.C. Tom is the moderator of Group 2, and he will present their findings.

THOMAS O. McGARITY: Let me first introduce the panel that we have picked from Working Group 2. At the far end is Bob Kaufman, from the Environmental Protection Agency in Las Vegas, Nevada; next to him is William Lochstet, from the Environmental Coalition on Nuclear Power, State College, Pennsylvania; next to him is Ian Forbes, from the Energy Research Corporation in Framingham, Massachusetts; then, Clyde Claiborne from Union Carbide in Oak Ridge, Tennessee; John Bartlett from Batelle, Pacific Northwest Laboratories in Richland, Washington; and Dan Egan, from the Environmental Protection Agency in Washington, D.C.

McGARITY: The first question, by William C. Remini, (Energy Research and Development Administration, Washington, D.C.) is "Using probabilities and/or consequences of abnormal or unplanned events, both natural and man-made, in the development of criteria and standards, precludes and rules out setting a zero release standard. Because one can develop a scenario of these high and low probability events to sequentially occur until there is some finite probability of release greater than zero, does this not then rule out the desire of some Group 1 panelist's views that zero release be established as the EPA standard?"

DAN EGAN: I think your comment that inclusion of probability and consequences ruling out a zero release standard under any situation is correct. I am sure you will note from the two presentations that there is a difference of opinion in the conclusions reached by Group 1 and Group 2 regarding the appropriate considerations of risk in the setting of criteria and standards. All we can offer as an explanation is that we were in two different rooms and Group 1 did not talk to Group 2 until about 1 a.m. this morning.

H. CLYDE CLAIBORNE: We, that is the Office of Waste Isolation, have plans for a repository. Our intention is to design for zero release. That is, when all the geological and hydrological factors indicate that this formation will be leak tight and stable for millions of years, then we will say that it is a suitable site. We do not expect any release at all. You might say we are designing for a zero release. However, we recognize the fact that there is a probability that some of the evidence or some of the data were insufficient to make an

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accurate prediction and some occurrence could happen. Therefore, we undergo the risk assessment to answer the "What if" question. Thus, we have a zero release design. I am speaking, of course, of the sealed phase, the long-term phase. Yet one is trapped by the semantics in saying it is not a zero release design because we are considering the "What if," that is, the accident.

McGARITY: The next comment I have is from E. W. Murbach.

E. W. MURBACH (Allied General Nuclear Services, Barnwell, S.C.): First of all I would like to commend you for this paper. I think you did a good job. I have three minor comments. At the bottom of page 2-76 you say it was pointed out that we do not know the health effects of background levels. Well last year I looked at a cancer map of the United States and frankly I could not see a bit of difference between the Colorado/Wyoming area, where the people live at twice the natural background, and that of South Carolina where I live. I think that goes back to what is considered one of the disasters--the linear, no-threshold hypothesis.

McGARITY: Would anyone like to address that?

WILLIAM A. LOCHSTET: I think most of the group felt that to redo the BEIR report was not our project. That would be put into the body of knowledge which EPA would use in setting the standard.

MURBACH: Then on the top of page 2-79, I would like somebody to amplify. You say "likewise the ambient radiation levels rising from foreign nuclear activity should also be considered in the ultimate development." Can somebody amplify what you mean by that?

ROBERT KAUFMANN: I think the thought behind our raising this issue and all the issues is not that we hold to any of them, but that they are concerns we have on our mind. We are using this forum to see if the feeling is to amplify or reject them. I believe the environmentalists are concerned that international activity will cause ambient radioactivity to increase, and that it would be ridiculous--case in point, the recent Chinese atmospheric testing--to just deny that in our standard. I think we are becoming increasingly aware that we affect other countries and that they affect us.

MURBACH: I agree, but let us take an extreme case--suppose that by shooting something off, a country managed to increase the natural background by 10 percent for the next five years. Does that mean that we would have to shut down and not do anything?

KAUFMANN: No.

IAN A. FORBES: Maybe it might be worth briefly summarizing where this came from. It was a long, involved discussion; I will not go into detail. A question was raised in our discussions whether standards ought to consider releases to the ocean, and whether that meant leaching from a geologic repository out into the ocean or ocean burial. From that question of ocean burial we got into consideration of ocean burial by other nations and whether that should be considered in these standards. There was no consensus other than that we felt it was worthy of further consideration.

McGARITY: There was a point on which we reached a consensus that is not reflected in this report.

STEPHEN ANDERSEN (Sierra Club Research, San Francisco, California): The consensus was that we would not relax standards because of increases in ambient levels of radiation. If anything, it would mean what you said originally: that if levels got too high from external sources, we would curtail releases in the United States.

MURBACH: My last point--the middle of page 2-81 says, "It was suggested that benefits of nuclear activities largely accrue to current generations. Well, it is my feeling that if all of us do our job right, we have perhaps offered something of benefit for better than 1,000 years, assuming the breeder ever comes to fruition. That figures out to something on the order of 30 to 40 generations that could have the benefit of nuclear power.

McGARITY: The next comment we have is from Stan Lichtman. He says, "Please describe the reasoning for giving 'priority to commercial high-level waste' on page 2-82."

FORBES: We actually discussed at one point what we meant by the term priority and recognized that there are two types of priorities. One is the schedule in which one has to take the various standard and criteria setting; the other is the priority that one might assign to the potential consequences from different sources of waste. What we mean in this instance is the recognition that the waste management programs at this time require that EPA give first attention to the setting of standards for high-level geologic disposal.

McGARITY: The next question is from Robert Schainker.

ROBERT B. SCHAINKER: Two items; one a little on philosophy and one just a very simple matter. The first item is that in general the topics of this particular panel were extremely more technical than some of the other panels. Consequently, a lot more jargon and technical terms were used. In terms of the general acceptance of the methods, the approaches, and letting the public understand our ideas, I think we have to find even simpler ways of explaining ourselves than what has been presented. I was talking earlier to a journalist, and we have a very, very difficult problem, but we should at least attack it to bring some of these concepts into very simple language. I think you did a phenomenal job but it still went over the heads of a lot of people. One way of simplifying things is that when you come with a question you are addressing, put your answer up front and your description later. It takes quite a while to understand whether there was a "yes", a "no," or a "maybe." One way of settling this problem is by stating your answer first. I read the question after I listen to what you wrote and I am still not sure if you answered the question. Or they gave me a lot of good information, and that is good information but it answers a different question. It is just an observation of mine. Now to the simple matter; on the very last page, you used the word "precision," and I think you really mean the word "accuracy." Both terms are well defined in statistics. But you say here, "The methodolgies of benefit cost, benefit-risk, fault tree, event tree, and consequence analysis provide guidance but not necessarily precision with respect to waste management decisions." You really mean "accuracy" because they all have great precision but they are not necessarily accurate at all.

JOHN BARTLETT: We mean precision.

SCHAINKER: Let me define my terms, gentlemen. Accuracy is referred to as the truth, a deviation from some hypothetical true solution to a given problem; whereas precision is a representation of the, shall I say, small amount of uncertainty about using a given calculation approach. You could think of it as a needle on an instrument. The needle may vibrate very little and have very good precision, but the instrument may not be calibrated correctly. Therefore, it may be entirely inaccurate and yet have great precision. Now which term do you mean?

BARTLETT: Precision, in the sense that the error bands are anticipated to be large even though you have come up with a highly deterministic number. The error bands are large. But we do anticipate that the accuracy in sense of order of magnitude is pretty good.

SCHAINKER: I think you may then want to define your word precision. It turns out the word you are using for precision is the word I use for accuracy.

BARTLETT: No, I am quite confident that we know the definition of accuracy and precision, and that we prefer precision.

SCHAINKER: Well, I think I will discuss this matter with you a little later. But one point is that you could define your terms. There is a whole set of terms called "fault tree," "event tree, and "cost-benefit." I have been aware of such terms some of these papers but I am sure the general public does not know what those particular techniques mean, although they are in WASH-1400 and some other documents. Thank you.

KAUFMANN: I would like to comment on that. Some of the ideas that were behind making up the issue paper and assemblying the panel to take on those issues I will take credit or blame for. I was extremely pleased with the cooperation we got from the floor and from the panel. Trying to put seven people together that are exemplary of the issue area is impossible. Hopefully, if there are shortcomings, we can make up for it in Albuquerque. The environmentalists on the floor and one or two that are here now are quite educated. I think that when we look at their growth we have come down perhaps to a slightly less technical level, but they have done a tremendous job in coming up to our level. They ask good questions, they expect good answers. I do not think we can address our work to the person reading the *Daily News*; it is just impossible. Now, I feel that the consensus that the American public is looking for is going to come from the Federal agencies pulling together, and I believe that consensus of Federal agencies will also carry the legislators. I think the decision and the agreement have to be reached at the Federal agency level and, of course, with industry, and that will carry the public and the legislators. That is my own opinion. But that was behind the way we organized and our willingness to take on tough questions and to try to develop consensus on tough questions. I do not think you can reduce a lot of these things to the public, any more than when I go to a medical doctor for treatment, I can understand every last thing he does for me, with me, to me.

McGARITY: I would point out that there was no attempt made to do that, to reduce this to...

SCHAINKER: I appreciate the efforts involved and the intentions and I understand that. But I think that there are some philosophical points that you raised right now that should be brought up as very important items to be considered at the next Workshop, one of them being: Is it really impossible to inform the general public about these issues? You just stated that in your opinion it is impossible. I can respect your opinion, but that issue may be at the foundation of some of the acceptability points of view of this entire nuclear issue. And that is a very, very important issue that should be brought up.

McGARITY: That point was raised, I can say, and it is discussed in the paper when we talked with regard to question 7 on acceptability. The consensus was that it should be phrased in terms--whatever the output of this risk analysis was--that are understandable to the decision-makers and/or the general public.

FORBES: I think that is an important point to stress, and I think you should read question 7 in more detail because we construed risk assessment to mean that detailed calculation of probabilities and consequences, which is by necessity a fairly detailed, technical subject. We said, however, that for the purposes of determination of acceptability and translating the detailed, technical methodology to the public, that was another step again, and that required such things as comparing the risk of waste disposal to other things. We recognize that, and I think you will see that attacked in question 7.

McGARITY: There is something that did not come out, though, which there was consensus on: that the assumptions that went into these should be made clear to the decision maker and/or the public.

McGARITY: The next question came from Mr. Meyer. "It was suggested that study of comparative risks of nuclear and nonnuclear ... would perhaps give a better perspective on the waste management issue."

SCHAINKER: Thank you, gentlemen.

G. LEWIS MEYER (Environmental Protection Agency, Washington, D.C.): Well, that sentence did not seem clear to me. Nuclear or nonnuclear what?

McGARITY: There is evidently a word left out. It would probably be power generation or something of that sort.

MEYER: Not necessarily.

McGARITY: Slightly prior to that we discussed whether we meant that the comparison should be between just the waste cycles of either cycle or between the full cycles and there was no consensus on that issue. Maybe that clarifies it. The next comment is from Frederick Forscher.

FREDERICK FORSCHER (Energy Consultant, Pittsburgh Pennsylvania): I really wanted to say the same thing that Mr. Schainker has brought up before, and that is that too much emphasis was placed on the quantitive risk analysis. It is nice to recognize that there are techniques to analyze these risks, but it must be realized that, from the decision-maker's point of view, and from the point of view of the public which has to accept the decisions, risk analysis can only be about 25 percent of this decision. There is the perceived risk, there is the quantified risk, there is the perceived benefit, and the quantified benefit. We have concentrated in this paper too much on the quantified risk analysis. Only in the last page do we get into the realization that it is not as complete and as satisfying philosophically as well as quantitatively as one would like to have it, and therefore there are other inputs necessary. One, for instance, is the suggestion of compared fuel cycles, nonnuclear and nuclear. I would like to see this too. This again depends not only on the quantified risk but on the perceived risk in fossil-fuel cycles as well as the perceived benefits of the fossil-fuel cycles.

McGARITY: Any comment on that?

LOCHSTET: I think from the point of view of setting standards, what you are interested in is the way nature is, not the way people think nature is.

FORSCHER: It is possibly philosophical, but scientists are trying to find out what nature is all about. Yet in certain criteria and standards they are making decisions. A criterion is a decision; as much a decision as the law is a decision. Congress makes decisions. We hope that the congressional decisions as well as the ones made by regulatory agencies on criteria are acceptable. And what we are talking about from the public point of view is the acceptability of these decisions. Acceptability is the balance of benefits to risks. The public will accept the decision if the benefits exceed the risks.

BARTLETT: I think if you look at this issue in its entirety and if you had attended this session, you would find that indeed there runs through the whole thing the thread of recognition that risk assessment is by far not the total answer to the question. The session was specifically addressed to the question of what methods of risk assessment might be used and the variations within the uses of those methods. I think we did have a proper perspective of its limitations but we had to report for purposes of this being a tool to EPA as what we think in terms of its use as a tool.

FORBES: I think that is important to stress....Just to read the title, "Risk Consideration of Radioactive Waste Management" emphasizes that we were constrained in this session to look at risk analysis. As far as we could, we tried to stick to that topic. We got off it frequently, but certainly tried to point out that risk analysis was not the basis for decision making.

McGARITY: There is another comment by Mary Nightlinger (League of Women Voters, Fairfax, Virginia) that seems to be pretty much of the same order. Would you like to address it nevertheless? Okay, I will read your comment. "Most of the recommendations of this session centered on systems analysis approaches. These methods try to reduce all issues to numerical comparisons. As many of the necessary comparisons are not truly capable of being expressed in numerical terms, the resulting comparisons are sometimes not very meaningful. When these numerical comparisons are addressed by the press and the public, any warnings will fall through the cracks. Therefore the potential to mislead is very great. The Envrionmental Protection Agency should be very careful that in its effort to make things clear and simple, they do not end up making misinformation clear and simple."

Finally, the last question was from Judith Johnsrud (Environmental Coalition on Nuclear Power, State College, Pennsylvania). The question was "Did your group distinguish, in setting priorities, between military and commercial wastes?"

LOCHSTET: I think some of us tried to talk about the difference in the way in which decisions after the standard was set might make a difference. That is, this was something where we sometimes thought of the difference and sometimes did not. A curie is a curie, regardless of where it came from. But there are curies which are here, and there are curies which are not yet here. I think we had some of that in mind.

McGARITY: There was some discussion of it; it was mentioned but it really--and it was probably my fault--got muddled a bit. The place where it should have been considered is in a risk-benefit context, and we did not really get into that too much.

KAUFMANN: I would comment that I think there was a feeling in the room, and please tell me if I am not representing that feeling, that we were trying to find out if we should take on all wastes simultaneously with the same emphasis...or should there be some order of priorities? And the order of priorities that I feel was expressed by more than one member was that we look at high-level wastes, and that a clear distinction between commercial and Energy Research and Development Administration was not in order but that a clear distinction between high-level and other type wastes, was in line with Dr. Maxey's comments on the opening day and others. Let us get the worst problem in order first.

FORBES: I am not sure we concluded that high-level waste was necessarily the...well, perhaps "worst problem" is a difficult thing to define. We agreed that in terms of schedule, that had to be tackled first. We did not spend time discussing exactly on what basis, perhaps because we got consensus and that was good enough so that there was no point in trying to find out why. We agreed in terms of schedule but let me stress that we tried to differentiate between that priority in terms of the order in which one would tackle things and a priority in terms of which most needed tackling. It was agreed that all wastes should be treated on an equitable basis--whatever that phrase means--that there would be the intention to go on to subsequent wastes. I think it wasn't always clear. Certainly in our session, I think in some cases we were discussing all wastes and in some cases we were discussing only commerical, high-level, and even specifically geologic wastes. But certainly the intention was that all wastes should be considered on an equitable basis and that the first item that has to be tackled is high-level waste. But that does not mean that everything else should not be considered in terms of another priority for the need to be tackled.

McGARITY: That concludes our presentation.

WORKING GROUP 3

LONG-TERM IMPLICATIONS OF RADIOACTIVE WASTES

LONG-TERM IMPLICATIONS OF RADIOACTIVE WASTE MANAGEMENT: A STATEMENT OF ISSUES AND OBJECTIVES

This working paper identifies the long-term radiological considerations for radioactive waste which will have a direct bearing on the proposed criteria and subsequent standards. Two specific areas are to be addressed: (1) institutional longevity (or lack thereof) and its potential impact on radiological exposure levels, and (2) the dose commitment to future generations which would result from present decisions regarding the range of available waste management alternatives. While present wastes pose an immediate problem, the unavoidable reality of physical half-life (in some cases a very long half-life) will leave future generations with a potentially very real and long-term future problem. Though gazing into the future a million or even a thousand years is at best a speculative exercise, it should be remembered that the aim of this effort remains the identification of those factors contributing to the long-term radiological impact of radioactive waste management activities.

INSTITUTIONAL LONGEVITY

The previous generation has left a legacy of large amounts (in terms of both volume and curies) of radioactive waste material. This waste is primarily high-level waste and transuranic-contaminated waste from weapons development programs, although it does include waste of the entire range described in the previous section. With the expansion of energy generation by nuclear means (an activity generally foreseen to continue for at least the next few generations), the present generation is adding, at a significantly increasing rate, to the expanding inventory of radioactive waste material on hand. The question yet remains unanswered as to precisely what is to be done with it. The choice is one of whether to make the decisions now to somehow commit the radioactive waste to long-term management or merely pass it on to the next and future generations, much as this generation has inherited the waste of the previous generation.

A common approach used in assessing the impact of a proposed or projected activity is cost-benefit, risk-benefit analysis. When dealing with radioactive waste management, this mode of analysis seems to break down. The more tangible benefits of nuclear and nuclear-related activities, i.e., those resulting in the generation of radioactive waste products, appear to be realized only in the present and immediate future, while the risks associated with the resulting wastes extend far into the future. The argument that future generations will benefit from present technological development assumes continuing technological growth, but this may be of little consolation if we leave to the future the responsibility

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for handling both the present waste and that which will be generated in the course of the expansion.

Another argument is that by present utilization of existing nuclear resources, valuable fossil fuel resources will be conserved for future applications, perhaps more specific and beneficial than merely using these resources for their heat content. This implies that there might indeed be a future benefit associated with present activities generating radioactive waste. However, this argument too may not be entirely valid, for while such a scenario will conserve fossil fuel resources for use by future generations, these resources are limited and will in all likelihood be consumed long before the risks associated with nuclear waste (past, present, and immediate future) will have been reduced by natural radioactive decay processes to acceptable levels. Also, there remains the question of whether "buying time" in terms of the overall energy picture by developing and utilizing the nuclear fission economy is worth the price of the resulting and unavoidable thousand to million years during which waste management may be required. Regardless of the future of nuclear activities, however, a waste disposal problem remains, primarily in the form of the stored ERDA wastes and uranium mill and phosphate benefaction tailings.

These considerations lead to the realization that present indecision will only prolong the problem of radioactive waste management and compound future risks. The implication here is that while state-of-the-art technology may lead to less than perfect solutions to the waste problem, the present generation should make a concerted effort to formulate and implement a waste management program. Failure to do so would only perpetuate the risk of waste release and resultant population exposures.

A question arises as to the duration of the radioactive waste problem. As a general rule of thumb, it can be assumed for the most part that transuranics pose a "million-year" problem, while fission and activation products pose a "thousand-year" problem, and that after these respective periods the wastes will have decayed to acceptable levels. Carbon-14 and iodine-129, both long-lived fission products, are two principal exceptions. The duration and magnitude of the problems associated with radioactive waste can be reduced by partitioning (separation of transuranics from other isotopes), fractionation (separation of short- and long-lived products), and subsequent transmutation. Through such processes, the overall waste management problem could possibly be reduced from a million-year one to a thousand-year one.

One option which has been proposed as being applicable to both the relatively short-term and long-term problems is isolation via placement in geologically stable formations.

Subsurface salt beds have been identified as having many advantages necessary for such isolation including long-term stability, ability to recrystalize upon fracturing, and ability to withstand heat stress. However, the evaluations by the Atomic Energy Commission of disposal in an abandoned salt mine near Lyons, Kansas, pointed out the uncertainties associated with this disposal option. Although such geological formations provide relatively good stability against the forces of nature, the effect of the various activities of man on such stability is less certain.

Two other basic options have been offered as potential solutions to the million-year problem: transmutation and disposal in outer space. There are uncertainties, however, associated with each of these alternatives. An integral step in transmutation is partitioning. However, it is uncertain as to whether the waste volume will be reduced or whether the required chemical processing will actually result in an even greater, although separated, volume of waste to be handled. Efficiency of separation processes is another area of uncertainty; some of the long-lived products will be carried over into the short-lived waste stream. Transmutation is a concept that is yet to be proven on a production scale. There is uncertainty as to the energy input required to achieve transmutation and the types and amounts of additional waste products that would result. In disposing of the long-lived materials in outer space, there are doubts as to payload capabilities and our ability to provide adequate safeguards to assure that launch pad failures and/or reentries either will not occur or, if they should occur, would not result in releases of radioactive materials to the biosphere.

While projections or speculations can be made on further technological advances to overcome these obstacles, such technology does not presently exist. Because of the pressing need to address the problem of radioactive waste management in the present, utilizing state-of-the-art technology, it is the million-year program which has received the most attention to date. This does not imply that all future waste will necessarily be committed to the million-year concept ultimately to be formulated. As technological advances are made, it can be assumed that the waste management program will correspondingly evolve. Concomitant with this assumption should be the understanding that the long-term integrity of wastes disposed of by the various methodologies discussed cannot, for the most part, be assured for the hundreds of thousands or millions of years required. At best, it would be a probabilistic assurance of containment integrity. It has been suggested that it would be more reasonable to ensure that in the event of a containment failure, the length of time required for the material to impact the biosphere would be sufficient to allow the vestigial radioactivity to decrease to background levels. This is the "return to a natural state" concept.

An area of great speculation concerns the state of intelligence and technology which will prevail in future generations. Three basic positions are commonly put forth: future intelligence will be at least equal to present intelligence and, thus, be able to cope with and manage our waste repositories; the intelligence of future generations will surpass that of present generations and therefore our waste management problems should be deferred to them; and intelligence in the future will regress and therefore future generations must be protected from our waste.

None of these views has gained full support as representing the approach which should be taken with regard to radioactive waste management, but at the same time each position has been viewed as encompassing at least a part of what the overall approach should be. There is no way of accurately forecasting either the future stability of institutions or the future state of intelligence and/or technology. Due to the uncertainties in these areas, it has been suggested that all decisions regarding waste management should be made independently of any and all speculation with regard to these questions. While it is possible that future generations may be better able to handle the waste problem than the present generation, it is questionable whether the present generation has the right to make this assumption and merely defer the problem unsolved. At the same time, if the waste management problem is passed on unsolved, the risk is run that it will remain unsolved.

The implications of these considerations are that the present generation, to the best of its technological capabilities, should establish and implement a waste management program which would isolate past and present radioactive waste from the biosphere and minimize the environmental impacts resulting from such a program. Moreover, these goals should be achieved without dependence upon the future stability of human institutions. If this were possible, the present generation would remove itself from all involvement in speculation as to future conditions and would protect future generations from our radioactive waste. This is based upon two basic assumptions: (1) that a disposal concept can be designed and implemented in such a way that the probability of natural or accidental disruption will be minimal, and (2) that intentional intrusion will not be attempted by future generations (the latter assumption perhaps quite optimistic).

There have been various arguments as to what conceptual approach should be taken to guarantee the effectiveness of these efforts. One opinion holds that the adopted concept should be such that accessibility and retrievability of committed waste would be, for all intents and purposes, impossible. While this solution, in time, may not prove to be the best, and while future technological advances may result in better methods for waste disposal, the argument is that at least the present generation will ultimately protect itself and future generations from our own waste, and do so in such a way that future generations are not relied upon to either achieve or continue this goal. At the same time, however, the concept of retrievability has gained support as permitting the present generation to manage its waste, while leaving the options left open to future generations to perhaps better handle the waste.

The question of institutional longevity is a major one in the determination of the nature of the waste management concepts to be pursued. In considering a concept in which human interaction over long periods is involved, there are uncertainties as to: (1) the stability, continuity and perpetuity of recordkeeping; (2) the ability to assure long-term caretaking and safeguarding of a respository site; (3) the ability to assure continued capability for surveillance and accident response; and (4) the long-term accessibility and capability for retrieval. These areas of uncertainty are associated with any long-term "storage" concept. While it may be argued that the necessary institutions will continue to exist in perpetuity, the other side of the argument may be just as easily advanced: Can one reasonably assume that such institutions as governments and national boundaries will survive the time periods over which the waste must remain isolated? In either case such arguments may result only in unnecessary and unsubstantiated speculation.

Over the relatively substantial time periods relevant to the long-term management of radioactive waste material, it has been generally accepted that nature has been more stable than human institutions. Rather than designing a waste management program around the uncertainties of human institutions, it may be more advisable to design the system in such a way that the isolation of the radioactive waste material is entrusted to nature. After an initial validation period, human involvement will become peripheral (though perhaps desirable)--not a necessary activity in assuring the isolation of the disposed waste from the biosphere.

DOSE COMMITMENT TO FUTURE GENERATIONS

With regard to the dose commitment to future generations resulting from waste management activities (or lack thereof), one is faced with the fundamental question: To what maximum level of radiation exposure are future generations to be exposed? There is first a fundamental problem associated with the determination of such a level, for no guidelines have been developed for current population exposure from this source. Assuming the existence of such guidance, however, there are basically three possible answers to this question: more, less, or the same as allowed the present generation. In weighing these possibilities, a consideration that should again be kept in mind is that the more tangible benefits derived from the activities responsible for generation of the wastes are enjoyed primarily by the present generation and in the immediate future.

While the arguments seem almost entirely philosophical, it is generally accepted that to commit future generations to higher levels of radiation exposure than the present generation is willing to accept is unjustifiable. To do so would be even more unconscionable in view of the complete lack of derived benefits to future generations from present waste. Further, by passing on this commitment without benefit, future generations are perhaps deprived of the option to develop future activities from which they might derive direct benefits.

To say that future generations should be exposed to the same level of radiation from the storage or disposal of radioactive waste as is allowed the current generation is a specious statement. For with the exception of the "as low as practicable" guidance, there is no presently existing guidance to apply to such exposures (assuming extrapolation of this guidance to the waste management area is even valid). Assuming there were an established numerical limit for radiation exposure due to waste management activities analogous to the uranium fuel cycle and drinking water standards, there remain several areas that require consideration. These include the question of projected exposures, the potential for buildup of radiation-induced genetic defects, and the irreversibility of dose pathways.

If dose commitments due to waste management activities to future generations either in excess of or equal to presently acceptable levels are deemed unacceptable, the question arises as to just how low the future dose commitment must be before it will gain acceptability. One approach would be to start with a management concept which would yield a relatively high dose commitment and through application of technological improvements reduce that dose level. Another more conservative approach which could be taken in formulating a waste management program would be to start from the basis of zero-release and zero-dose.

The first step in analyzing the zero-release, zero-dose concept would be to establish the feasibility (or lack thereof) of achieving these goals. It can be assumed that over the geological time-frame which must be considered for any waste management program, it would be impossible to assure, beyond doubt, that no releases and no resultant dose commitment would occur. The problem then becomes one of determining what minimum upper limit level can be feasibly achieved within the scope of presently existing or foreseeable technology. Here, there are basically two factors operating in opposite directions: the increased cost required to achieve lower limits versus the societal pressure to achieve levels as low as technically possible. Cost-benefit analysis in the classical sense would not seem to apply, for again the "benefits" derived from a waste management program are of a somewhat negative, or at best, passive nature. It appears the solution will be more costly than what would be generally considered "cost-effective." But it will be one which should result in release and dose levels that, while not absolutely zero, will be close enough to zero to gain support as being "not unacceptable."

SUMMARY OF CONSIDERATIONS

The considerations which have been identified and discussed in the preceding text are summarized in addition to others expressed in various papers and reports in order to facilitate review. They are not necessarily listed in order of priority, and as they reflect merely one group's efforts (i.e., EPA's), they obviously do not represent a complete list:

1. Should the present generation commit itself to formulating and implementing a waste management program based upon a disposal concept or will long-term storage suffice?
2. Should the proposed program use state-of-the-art technology, or should yet-to-be developed technological capabilities (e.g., partitioning, transmutation, deep-space disposal, etc.) be relied upon as near-future realities?
3. How should waste immobilization be achieved?
4. Should past and present waste be committed to irreversible disposal or should options be left open for future generations to improve upon our program for the management of these wastes?
5. Should the proposed waste management program be designed in such a way as to be operable--to the greatest extent possible--independent of institutional surveillance and control? Should institutional activities beyond an initial "proof-of-effectiveness" period be viewed as peripheral convenience, if available, but not necessary for the continued safe functioning of a repository into perpetuity (such activities would include recordkeeping, caretaking, safeguarding, surveillance, accident response)?
6. It is EPA policy to assume that all levels of radiation dose result in detrimental effects. Accepting such a policy, should the goal of the waste management program be zero-release, zero-dose?
7. Should reliance be placed upon nature for the stable isolation of the disposed waste rather than upon societal institutions?
8. Should achieving minimum upper level release and dose limits which can be considered as being "not unacceptable" be the overriding design consideration

rather than cost-benefit considerations?

9. Should waste management criteria be generally applicable to all forms of existing and future radioactive waste material?
10. Should consideration of potential long-term hazards for various management options take priority over present concerns over near-term risk and cost?
11. Should the concepts of multiplicity of sites and diversity of options be implemented as a means of limiting the impact on future generations due to the potential failure of a particular disposal site and/or technology?

CONTROL OF RADIOACTIVE WASTES: ISSUES, PROBLEMS, AND QUESTIONS

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The Environmental Protection Agency (EPA) is to be applauded for convening this Workshop and exercising its proper role in the establishment of criteria and standards regulating the storage and disposal of radioactive wastes. The EPA is virtually alone among Federal agencies with programmatic responsibilities in vigorously seeking meaningful public input. Unfortunately, because the Office of Radiation Programs has been unable to obtain appropriate funding, citizen participation in this Workshop will be less than desirable. The new administration is urged to correct the past imbalance created by the financial difficulties for ordinary citizens to attend and participate in workshops such as this one.

The two Federal agencies principally responsible for the promotion and regulation of nuclear power, the Energy Research and Development Administration and the Nuclear Regulatory Commission, respectively, are focused exclusively on how to provide facilities permitting rapid growth of nuclear power and on how to license more nuclear facilities. The recent actions of the Nuclear Regulatory Commission in trying to circumvent and overturn the findings and order of the United States Court of Appeals for the District of Columbia Circuit are particularly troubling. That court, in its July 1976 opinion, stated that:

> The Commission's action in cutting off consideration of waste disposal and reprocessing issues in licensing proceedings based on the cursory developments of the facts which occurred in this proceeding (generically considering the environmental costs of radioactive wastes) was capacious and arbitrary.

Instead of trying to correct the serious deficiencies identified by the court, the NRC response has been first, to ignore the plain meaning of the court's opinion by issuing an interim rule and permitting full power licensing without more than a superficial notice and comment proceeding, and, second, to appeal to the U.S. Supreme Court, even though the U.S. Department of Justice decided an appeal was not appropriate. Indeed, the Department of Justice has filed a legal brief with the Supreme Court urging that it not accept the NRC's appeal for review. With this kind of disregard for the law and the public interest at the NRC, the Environmental Protection Agency's activities are particularly important.

My presentation is divided into two parts. The first part reviews very briefly some of the more important general issues and problems associated with the need to exercise extreme control over radioactive wastes. The second part addresses the specific questions raised by the Environmental Protection Agency in its background statement for this Workshop.

Current programs for handling radioactive wastes in the United States stand in disturbing disarray. The situation has reached a critical point in determining the viability of the nuclear power industry and the safety of future generations. Unless substantial improvements are implemented in conjunction with the proposed rapid development of the nuclear option, the risk of releases of radioactive wastes to the environment may become unacceptable.

A total management policy for radioactive wastes must deal with varied and voluminous wastes, all posing different and difficult handling and storage problems:

1. The nuclear fuel cycle begins with the mining and milling of uranium ore, a process which yields a semirefined compound of uranium (U_3O_8) for use in the fabrication of fuel rods, but leaves behind massive piles of "mill tailings." These tailings consist of a sand-like residue, containing the hazardous and long-lived natural radionuclides thorium-230 and radium-226, in a form relatively easily dispersed by wind and water. Methods must be devised to prevent natural processes from dispersing this dilute but dangerous material.

2. Low-level wastes result from the routine operation of nuclear facilities. They in general consist of discarded materials that have been contaminated in the course of normal operation of plants handling radioactive materials. Some government agencies have estimated that the nuclear power industry will produce hundreds of millions of cubic feet of this radioactive "garbage" by the year 2000. To date, disposal practices have indiscriminately mixed materials contaminated with extremely hazardous, long-lived radionuclides with materials contaminated with shorter-lived radioactivity. Moreover, management practices at many disposal areas have been notoriously inadequate, allowing some radioactivity to migrate away from one-third of the existing commercial disposal sites. Contaminated equipment has even been smuggled away from another commercial disposal site. Only recently has the government recognized the need to segregate contaminated materials according to their toxicity and the need to improve the safety of disposal operations.

3. Radioactive gases, containing iodine, carbon, tritium, and krypton, are released during the operation of power reactors and fuel reprocessing plants. There is no doubt that the proliferation of nuclear power plants requires that the bulk of these gases be trapped and not released to the environment. Precise containment plants have yet to be formulated, however, and obvious difficulties in storing dangerous gases intact over long periods of time have also yet to be resolved.

4. The radioactivity in "high-level" wastes, which have received the most public attention, are produced in the nuclear fuel rods during the course of the fission reaction in the reactor core. After these rods have been "burned" in the reactor for about three years, the industry plans to have the rods "reprocessed" to recover unused uranium and plutonium. Plutonium is a "fiendishly toxic" element with a half-life of over 20,000 years, which can also be used to fuel reactors or to make nuclear bombs. By dissolving the reactor's ceramic fuel, however, reprocessing also produces a highly radioactive liquid waste product that must be isolated from the biosphere for hundreds of thousands of years. A precise plan for converting the high "burn-up" commercial liquid wastes to a solid form has yet to be developed. Indeed, the nuclear industry has asked the Federal government to build the first "commercial" solidification facility in order to demonstrate to industry that solidification can be accomplished safely and economically. Evidently, the uncertainties are too great for the industry to risk its own funds. Continuing government efforts to identify an acceptable site to bury these wastes deep within the earth have also yet to be successful. All we have now are past failures and milestones on charts indicating current plans and future hopes.

5. Finally, the need to decontaminate and decommission all nuclear facilities will also produce significant amounts of radioactively contaminated material. Virtually no work has been done by either government or industry to identify acceptable means of disposing of these materials.

No fully acceptable disposal means is currently available for handling any of these categories of wastes. Beyond the significant technical obstacles to devising acceptable disposal methods, major barriers to implementation of adequate waste management programs come from institutional and human failings. A brief review of America's nuclear development reveals frequently ill-advised and, at least in hindsight, irresponsible decisions by the Federal government which have caused unnecessary delay and expense as well as unwarranted health hazards.

The Hanford Reservation in eastern Washington illustrates the lack of planning inherent in the former Atomic Energy Commission's (AEC) program for waste management. High-level wastes generated during the production of nuclear weapons have been stored at Hanford for the last thirty years, mainly in the form of liquids and "wet" solids. When these wastes were pumped into underground "mild" steel tanks, AEC officials and scientists purportedly recognized the short-term nature of such storage. Although the waste managers soon realized that the tanks had an effective containment lifetime of only 10 to 20 years, they continued to store the wastes in a form that could not be easily recovered. The net result has been several major releases of radioactivity into the ground; official predictions of future leaks from the disintegrating tanks; and no easy, safe way to retrieve the wastes for safe permanent storage.

The lack of adequate planning and analysis in the past is also reflected in the history of the government's weak efforts to establish a permanent repository for commercially generated, long-lived radioactive wastes. The search for the "ultimate" solution to the problem of perpetually storing high-level radioactive wastes from the commercial sector began shortly after passage of the Atomic Energy Act of 1954. From the outset, the AEC and its advisors focused on bedded salt deposits as the most likely geological formation in which to dispose of the long-lived wastes. In 1957, for instance, a special committee of the National Academy of Sciences-National Research Council agreed that "[d]isposal in salt is the most promising method for the near future." After several years of investigation and study on bedded salt, the AEC selected an abandoned salt mine near Lyons, Kansas, as the location for a pilot repository. The repository would have been a Federal facility because an AEC regulation that became effective in February 1971 required Federal custodianship of high-level radioactive wastes produced in nuclear power plants. (The need for Federal control is a testament to the long-term hazard posed by the wastes.) If tests verified the government's predictions of safety, the Lyons mine was supposed to become the first national repository for high-level radioactive wastes. For a number of technical and political reasons, however, the AEC formally killed its proposal for the Lyons salt mine on May 18, 1972.

The AEC then turned its attention to similar formations near Carlsbad, New Mexico. During the drilling of a third exploratory well at a tentatively-selected site for the pilot repository, scientists discovered a brine solution containing pressurized quantities of hydrogen sulfide, a very poisonous gas, and methane, a potentially explosive gas. The presence of the brine solution raises serious doubts about the long-term integrity of the salt formation and its ability to prevent migration of the waste materials. The pressurized gases possibly pose a very serious hazard to miners who would build the repository.

In response to this development the Energy Research and Development Administration (ERDA) has de-emphasized the importance of the Carlsbad area in its program for commercial wastes. Testing for a safer site in the Carlsbad area has recently begun again, however, while other types of geological formations are investigated throughout the country. At least initially, ERDA's intent appears to be to emplace only government transuranic wastes in the proposed Carlsbad repository.

First the Atomic Energy Commission and now the Energy Research and Development Administration have continued to underestimate the facilities and management techniques required for storage of high-level wastes. There are presently about 600,000 gallons of high-level wastes stored at the Nuclear Fuel Services reprocessing plant in West Valley, New York. These wastes were produced during the plant's operation from 1966 until 1972, at which point it was shut down for modification and expansion. But there are still no plans for disposal of the accumulated wastes. Recently, the Nuclear Fuel Services Company has informed the State of New York that it wishes to transfer ownership of the high-level wastes to the state. This decision follows the release of a Nuclear Regulatory Commission report that retrieving the wastes from the tanks and solidifying them may cost 500 million dollars, or far more than the income from reprocessing and the worth of the plant.

There are essentially two possible underlying explanations for the lack of an adequate means or plan for the disposal of all kinds of radioactive wastes. Either the Federal bureaucracy is to a large degree incompetent or the radioactive waste disposal problem is considerably more difficult than has been publicly admitted by the nuclear power industrial complex. Both explanations are largely supported by a careful examination of the record.

As the country prepares to turn to nuclear reactors for much of its energy requirements, there is ample reason for concern that it may be tragically short-sighted to generate wastes irrevocably now on the optimistic assumption that a solution to the threats posed will be found in the future. There should be no delay in undertaking a wide-ranging, in-depth review of ERDA's proposed waste management program and the reasonable alternatives to it. The following recommendations deserve careful consideration.

First, we should slow the production of radioactive wastes until an adequate analysis of their hazards and management possibilities can be made. Since we cannot permanently dispose of these wastes now, prudence suggests that we minimize the amount of waste that must be handled until an acceptable disposal program can be developed.

Second, no reprocessing to extract plutonium from irradiated fuel rods should be permitted until several uncertainties are resolved. Trace amounts of plutonium have been shown to cause cancer in laboratory animals. Twenty pounds of purified plutonium is sufficient to construct an atomic bomb. Until serious questions regarding our ability to guarantee that plutonium will not pose an unacceptable health hazard and that it will not be diverted by terrorist or other groups for improper uses, we should not permit it to be recycled. Furthermore, no reprocessing of spent nuclear fuel should be permitted unless the liquid wastes will be solidified immediately in a format at least as secure as the fuel rods.

The reprocessing of fuel rods and fabrication of new fuel containing plutonium will generate a large number of waste streams that cannot be permanently disposed of now. The production of these wastes should wait until the NRC completes a thorough review of the overall waste management problem, as ordered by the U.S. Court of Appeals for the District of Columbia. It is far from clear that the complicated set of diverse waste forms originating in reprocessing plants and mixed-oxide fuel fabrication plants can be handled safely. If we are to continue reliance on nuclear power, the best alternative from a waste management perspective alone may be to forego the plutonium recycle option. At the least, this no recycle option is deserving of careful study, including public review, before the nuclear industry is allowed to expand on the assumption that recycle of plutonium will be permitted.

Third, we must improve our technical analyses and scientific review of alternative waste management options. There is a desperate need to decide explicitly the goals of waste management and to develop precise criteria for determining the likelihood that options under consideration will achieve these goals. The establishment of goals and criteria must involve a broad spectrum of scientific analysis. Experts in the relevant disciplines who are not now a part of the nuclear industrial complex must be given an adequate opportunity to review the research projects associated with the development of a waste management program. The purpose of this review is to insure that an adequate technical basis will exist for selecting a preferable waste management option that is consistent with the goals. The failure to allow the scientific peer review system to function in the past has lead to the current insufficiencies of the government's research program.

Again, I emphasize that EPA's program is very important in this regard. Increased review by both EPA and nongovernmental groups is required, however.

An example of the fundamental deficiencies in the data base is the lack of information about the geological behavior of radionuclides in a strong thermal gradient, such as will exist if containers of concentrated wastes are emplaced underground. Other serious deficiencies involve, for instance, solidification of liquid wastes and the decontamination and decommissioning of nuclear facilities.

Fourth, the Federal government should develop a "model" waste management program using its own millions of gallons of high-level radioactive wastes. These wastes will have to be stored securely regardless of the future of nuclear power. But before the commercial nuclear power industry expands further, the Federal government should demonstrate to the nation that it has the technical capability and the willingness to take care of its own wastes.

Fifth, there is a great need, and opportunity, to improve our decision-making process. Nuclear power, and energy policy in general, are social issues that cannot be decided by bureaucrats and technocrats alone. The public has demonstrated a growing interest in the future of nuclear power. Citizens and legislators must work with the scientists and bureaucrats who have traditionally determined our nuclear policy in order to establish a comprehensive set of objective criteria for judging the acceptability of various options. I hope that NRC and ERDA will follow and, indeed, improve on the example being set by EPA at this Workshop.

Radioactive waste management poses a classic trade-off of short-term versus long-term environmental quality. Actions taken to isolate radioactivity from the immediate environment have often proved to be tragically short-sighted when measured against long-term goals, as in the case of high-level wastes at Hanford and the Nuclear Fuel Service's West Valley plant.

To achieve an acceptable social and technical consensus on the best course of action, there must be regional, state, and local government and citizen participation in the review of alternatives for radioactive waste disposal. Until there is thorough consultation with the varied concerned segments of local and state governments, universities, and citizens' groups about the goals and criteria of waste management, the Federal program will continue to be embroiled in controversy. Had the government involved the public sooner in its decision to build a national waste repository at Lyons, Kansas, considerable expense and wasted effort might have been avoided.

Each state, particularly if it has or plans to have a nuclear power plant, should raise the important societal issues regarding radioactive waste disposal. The radioactive waste issue is too important for a state to define its interests

Regulatory Commission to consider fully the handling of radioactiave wastes during the licensing of nuclear power plants the states have a convenient opportunity for considering this issue.

Finally, we must examine the moral dilemma posed by knowingly creating such a long-lived and potentially lethal hazard to future generations. Frequently proponents of nuclear power point out that higher standards of safety and reliability are applied to nuclear power than to any other power source. This is, in fact, true, and can be justified for two reasons.

First, the toxicity of radioactive materials is much higher than other likely environmental pollutants. The long-lived nature of this radiotoxicity demands that we consider not only the environmental quality of our generation, but also that of generations a thousand or even a hundred thousand years hence. It appears untenable to assume that society will remain sufficiently stable to monitor and maintain our waste disposal sites for the requisite hundreds of thousands of years.

Second, nuclear power is a recent development, and one that has not yet proliferated beyond control. We have the opportunity at this point to plan our progress and avoid irrevocable commitments for ourselves and future generations. If we are to continue our quest for improved environmental quality, we must demand more of new technologies. It is not too late to decide, after careful examination and thought, that nuclear power is not worth the costs and risks of rapid development at this time.

To facilitate the exchange of information and viewpoints at this Workshop, EPA has prepared background statements that identify some of the important issues that should be considered by the discussants. Each background statement also includes a list of questions that need to be addressed by participants. In order to initiate the dialogue on these questions and to provide EPA with the information it is seeking, I list my initial answers to each question concerning the "Long-term Implications of Radioactive Waste Management" below.

Question 1. Should the present generation commit itself to formulating and implementing a waste management program based upon a disposal concept or will long-term storage suffice?

Answer 1. The major thrust of the government's waste management program should be to establish a waste disposal facility at the earliest possible time consistent with a thorough investigation of alternatives and site characteristics. For too long the government and the nuclear power industry have postponed selection of a waste disposal means. The current interim storage of long-lived wastes is wholly inadequate for protecting the environment and public health. The full cost of nuclear power must be clearly identified for those consuming electricity and internalized in the price of electricity. This can be partially accomplished by taking appropriate measures to dispose of radioactive wastes in the near future. Postponing the decision on ultimate disposal will only continue to externalize waste disposal costs.

Question 2. Should the proposed program use state-of-the-art technology, or should yet-to-be developed technological capabilities (e.g., partitioning, transmutation, deep-space disposal, etc.) be relied upon as near-future realities?

Answer 2. The available studies and data strongly suggest that existing technology is adequate for disposing of the existing and near-term production of long-lived radioactive wastes. We should not postpone the decision to dispose of wastes and the establishment of an actual disposal facility until so-called improved by speculative technologies are developed.

Question 3. How should waste immobilization be achieved?

Answer 3. For reasons only partially related to radioactive waste management, my opinion is that the preferred waste form is spent fuel. However, if the societal decision is to have reprocessing, then there should be immediate solidification of the high-level liquid waste into an inert, relatively non-leachable form, such as glass. The existing regulations should be changed to prohibit the scheduled storage of high-level wastes as liquids.

Question 4. Should past and present waste be committed to irreversible disposal or should options be left open for future generations to improve upon our program for the management of these wastes?

Answer 4. If the waste form is spent fuel, then for perhaps one to three decades, the spent fuel should be relatively easily retrieved for a deep geological formation. However, the storage conditions must allow human control to be lost without there being a significant possibility for release for large amounts of radioactivity. If the wastes are in a form other than spent fuel, then there should be no planning for the possible retrieval of the wastes after initial tests are completed.

Question 5. Should the proposed waste management program be designed in such a way as to be operable--to the greatest extent possible--independent of institutional surveillance and control? Should institutional activities beyond an initial "proof-of-effectiveness" period be viewed as peripheral convenience, if available, but not necessary for the continued safe functioning of a repository into perpetuity (such activities would include recordkeeping, caretaking, safeguarding, surveillance, accident response)?

Answer 5. The proposed waste management program must be designed in a manner permitting containment of the wastes independent of institutional surveillance and control. In my view, there is much greater certainty in predicting the future course of geological events than institutional or societal events. Institutions can be severely disrupted in the event of revolutions, economic depressions, war, etc. Over a period of many decades, institutions can also evolve into something that was not originally intended. Such modified institutions may actually be counter-productive in protecting the radioactive wastes. We simply don't know. We should not conduct the experiment to find out.

Question 6. It is EPA policy to assume that all levels of radiation dose result in detrimental effects. Accepting such a policy, should the goal of the waste management program be zero release, zero dose?

Answer 6. For deep geological waste repositories containing long-lived radioactivity, the answer is yes. While I do not hold that small releases of radioactivity would necessarily be unacceptable, there is no means by which we can reliably predict the magnitude of such releases from deep geological repositories. Therefore, we should design the high-level waste disposal facilities such that under likely conditions in the future there will be no releases whatsoever. Furthermore, there should be safety factors involved such that in the unlikely event some breach of containment does occur, the releases will be small. It makes no sense to me to establish a particular numerical limit other than zero for the reason that it would be entirely arbitrary and there would be no way of confirming that a facility could meet the proposed standard.

Question 7. Should reliance be placed upon nature for the stable isolation of the disposed waste rather than upon societal institutions?

Answer 7. Yes.

Question 8. Should achieving minimum upper level release and dose limits which can be considered as being "not acceptable" be the overriding design consideration rather than cost-benefit considerations?

Answer 8. We need both types of standards for radioactive waste management facilities. First, we should recognize that there are unacceptable levels of release that cannot be permitted under any circumstances. In effect, of course, existing regulations do establish such maximum permissible releases of radioactivity. Second, those measures that would be cost-effective in reducing radioactive releases even further than the minimum acceptable standard, should be undertaken. The analysis should be based on a comparison of the benefits of the proposed action in comparison to the cost. There is no rational basis for making comparisons to other ways that the same amount of money could be spent to achieve higher levels of human safety, as has been suggested by some. Such suggestions are simply red herrings. There is no mechanism for transferring monies that can be spent on improving the margin of safety for waste disposal facilities to other types of programs.

Question 9. Should waste management criteria be generally applicable to all forms of existing and future radioactive waste material?

Answer 9. Yes. In particular, the new EPA criteria and standards should be applied to the existing military wastes in storage at government facilities.

Question 10. Should consideration of potential long-term hazards for various management options take priority over present concerns over near-term risk and cost?

Answer 10. I strongly believe that future hazards should be compared to near-term hazards on a nondiscounted basis. In other words, if saving 10 lives at any time in the future means that we would have a cost of one life now, then we should save the 10 future lives.

Question 11. Should the concepts of multiplicity of sites and diversity of options be implemented as a means of limiting the impact on future generations due to the potential failure of a particular disposal site and/or technology?

Answer 11. At the present time it appears to me that we cannot have a sufficient number of sites such that the magnitude of a major release from any one of those sites would be acceptable. Furthermore, my guess is that the greatest possibility for failure of a waste repository will be due to the human failings in selecting a site and in designing, constructing and operating a repository, rather than in the deficiencies of properly selected geologic formations. I would rather have the country's best waste management talent, and, unfortunately, there just isn't enough of that, focused on only a few repositories to insure that they meet the highest possible standards. In this way, I would hope that there would be no significant possibility of a large release of radioactivity at any time in the future. If we were to go to the multiplicity of sites concept, the available expertise would be thinly spread. Certainly there would be less detailed oversight for each facility which professional societies and citizens' groups could provide. In my view, this lack of adequate oversight is likely to lead to less desirable facilities and, consequently, a great likelihood of an unacceptable release of radioactivity.

THE LEGACY OF RADIOACTIVE WASTES: INFINITY AND ZERO

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INTRODUCTION

My assigned topic is the legacy of radioactive wastes. In return for agreeing to talk on this subject, I received drafts of several Environmental Protection Agency (EPA) working papers. None had an author and each stated that it did not present an official EPA position.

The working draft on the long-term implications of radioactive wastes mentions two matters that may prove to be traps for the unwary criterion-setter. These matters are referred to in the working draft as the "million-year problem" and the "zero-release concept."

The long half-lives of radioactive wastes and managing these wastes in a way that permits no release are crucial to the legacy that we leave to our descendants. It is therefore appropriate that we consider these two matters here and now.

PERSISTENCE OF RADIOACTIVE WASTES

Consider first the persistence of radioactive wastes. You are all aware that some of the constituents of the radioactive wastes from nuclear power generation have very long half-lives. For example, iodine-129 has a half-life of 17 million years, but even this is not the full picture. Radioactivity, like Zeno's paradoxical arrow, gets half-way to zero in one half-life, three-quarters of the way in two half-lives, seven-eighths in three half-lives, and so forth. Like Zeno's arrow, which never reaches the target, radioactive waste never decays completely away. Viewed in this way, radioactive wastes present an almost infinite problem in that they never decay completely; hence the word "infinite" in the title of this paper. Fortunately, or unfortunately, depending on your point of view, it is not that simple.

One instructive way to consider the period of time important for radioactive wastes is to compare the toxicity of the wastes produced by a nuclear power reactor with the toxicity of the uranium ore from which the reactor fuel was obtained.

To make this comparison, the toxicity of the radioactive waste is expressed in terms of the quantity of water that will dilute the radioactive material to the concentration considered suitable for public drinking water (Ref. 1). These so-called maximum permissible concentrations have the merit of putting all radioactive materials on a common basis. Further, this is an appropriate way to express the toxicity of these materials. If they do reach the biosphere and man they will do so by being leached by groundwater, whether they come from buried wastes or uranium ore. Calculations of this kind have been made (Ref. 2,3) and show several interesting things.

The toxicity of the undisturbed uranium ore remains unchanged for many millions of years because it is controlled by the major radioactive parent, uranium-238, which has a half-life of some 4,000 million years.

For the first several hundred years after leaving the reactor, the toxicity of the nuclear wastes exceeds that of the ore, initially by many thousands of times. At just about 1,000 years the toxicity of the reactor wastes falls below that of the original ore.

But go back to the beginning for a moment. When the uranium was extracted from the ore, a small amount of unrecoverable uranium and essentially all of the radioactive daughters are left behind in the so-called tailings. The toxicity of the tailings, like the toxicity of the original ore, is dominated by radium-226. However, the decay of radium-226 is controlled not by its own half-life of 1,600 years, but by the half-life of its parent, thorium-230, which has a half-life of 80,000 years. As a consequence, the toxicity of the tailings decays with an overall half-life of about 80,000 years.

Adding the toxicity of the tailings to that of the reactor wastes gives the total for nuclear power. This total does not fall below the toxicity of the undisturbed uranium ore until somewhat more than 10,000 years after the power was generated, at which time one can say that the world contains less toxic material than it did originally, thanks to nuclear power. At about 1,000 years there is about twice as much toxic material in both the tailings and the reactor waste as there was in the original uranium ore.

At this talk of thousands of years leads quite naturally to one of two conclusions: either it is too long to risk, or it is too long to worry about. Before you chose between these, consider one further aspect of radioactive wastes.

Whatever is finally done with these wastes, they will be in a chemical and physical form far less likely to be dispersed in the environment than are the naturally radioactive materials in uranium ore. Further, they will be placed in geological formations far less likely to be leached by groundwater or otherwise disturbed geologically than is uranium ore. As a consequence of this care, the nuclear wastes are much less likely to reach the biosphere, even during the several thousand years before they become less toxic than uranium ore, than are the radioactive materials from the ore itself.

We do not have a million-year problem. With a modest amount of care, we do not even have a thousand-year problem. Infinity, or forever, is not as long as it seemed at first.

ZERO RELEASE

No method of confinement or containment is absolute forever. Water will dissolve even quartz in time, as the crystals inside a hollow geode attest. Forever is a long time and zero is a very small release. The criterion of zero release, if it is interpreted literally, will forbid any method of managing radioactive waste or for that matter any other waste.

Dr. Cohen (Ref. 4) of the University of Pittsburgh has estimated the cancer deaths, which might result from the random burial at 2,000 foot depths of all the radioactive wastes resulting from the production of 400 million kilowatt years of electrical energy (about twice the present annual consumption of electricity in the United States). He concludes that under these rather casual conditions there will be less than one cancer death in the first million years following such burial. He goes on to point out that the uranium which is consumed in producing this energy will reduce the amount of radium to which we are exposed and, as a result, will reduce the number of cancer deaths attributable to natural uranium by a number greater than the number of deaths attributable to nuclear waste. Here again, the world is better off for the fissioning of uranium.

Although less than one cancer death in a million years is about as close to zero as we are ever likely to get, it is not zero release. To paraphrase Lord Acton: Zero corrupts, and absolute zero corrupts absolutely.

Dr. Cohen concludes his article with a statement that goes to the heart of legacy.

> ...As our distant progeny look back on the late twentieth century, they will never notice the tiny amount (one part in 10^{10} in our model for each year of all-nuclear power) by which we will have increased the radioactivity in their environment. We will rather be remembered as the ones who consumed all the high-grade mineral ores--all of the copper, nickel, zinc, tin, lead, mercury, and so on--and worse than that, literally burned up at a rate of millions of tons per day those once plentiful hydrocarbons--coal, oil and gas--that are valuable as feedstocks for producing petrochemicals. The only thing that might save us in their eyes would be supplying them with a technology that will allow them to live in reasonable comfort without those resources; if we fail to do this,

we are indeed deserving of their curses. The key to such technology is, clearly, cheap and abundant energy, and unless great economies can be achieved in harnessing the radiation from the sun, the only source we have for this is nuclear energy.

SUMMARY

In summary, let us recognize that the criteria of infinite storage of radioactive wastes under conditions that guarantee zero release cannot be attained. Let us also recognize that there is no justification for either criterion. A reasonable expenditure of care and effort will assure that releases and any effects that they may cause will be entirely insignificant. Under these conditions, the legacy of radioactive wastes we leave to our descendants is a trivial problem, either in absolute terms, or in comparison to other burdens we are likely to leave them.

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LONG-TERM WASTE MANAGEMENT: CRITERIA OR STANDARDS?

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The topic of this section of the Workshop is long-term implications of radioactive waste management. I presume that the public is aware of what radioactive waste is. However, there is some disagreement as to what constitutes the "long term."

It is conventional when discussing nuclear wastes, and particularly high-level wastes (HLW), to speak of the bulk of the fission products as the short-lived components (Ref. 1). This is taken to mean that they will decay to "innocuous" levels in times less than a thousand years. With the notable exceptions of iodine-129 and technetium-99, the wastes said to present a long-term problem are alpha-emitters such as plutonium-239 or radium-226.

From a social or political perspective, it is difficult to think of 1,000 years as the short term. If we were to organize the management of wastes according to our ability to predict with some degree of reliability the course of human institutions, the time periods would be better divided as follows:

1. Short term - less than 50 years. Over this time, reasonably sure predictions can be made, not only about the stability, goals, and operation of human institutions, but also as to the degree of uncertainty in our projections of their behavior.
2. Intermediate term - one to two hundred years. Predictions can be made with some limited degree of confidence. These predictions are, like the previous case, based largely on extrapolation or projection of present trends. But, over such periods, the cumulative error owing to new circumstances and unforeseen developments can result in radical structural and policy changes. The degree of uncertainty in our projections also increases sharply, particularly with regard to events that are not predictable from the past or from present conditions.
3. Long term - greater than one to two hundred years. Uncertainties dominate predictive ability. For more than a few thousand years, there is only uncertainty.

These intervals are based on consideration of social structure and political and organizational lifetimes. The division based only on policy would be drawn at much shorter times. This division also corresponds reasonably well to three different ways of evaluating the intertemporal distribution of

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costs and benefits. In the short term, cost-benefit or risk-benefit ratios suffer from no more than the usual limitations: definitional problems with cost, risk, and benefit; equity; quantification of intangibles; and so on. These are extensively discussed in the literature (Ref. 2) and are included in the appropriate section of this Workshop. In the intermediate term a new element enters: intergenerational equity. Not only the distribution of benefits, but also the ethics of passing along risks and costs to our children and collateral descendants must be considered. There does exist, however, an ethical basis for evaluating our obligations. Those generations are our direct descendants. Our ethical obligation to them is based on an extension of our own obligation to our parents and our peers, and to the continuity of social, family, and political relations (Ref. 3).

In the long term both the intergenerational distribution of benefit, risk, and cost, and the ethical basis for our obligation to consider them, become less sure. The ethics of dealing with the future are, at best, imperfect. They have no basis in the traditional philosophic terms of reciprocity and self-interest (Ref. 3). Neither can we base our treatment of the future on economic or political equity (Ref. 4). If any finite discount rate is used, the present value of future harm is always nil for long periods of time. If all generations have the opportunity to vote, ours could never act at all on issues affecting large numbers.

The internal processes by which decisions are made cannot and do not systematically provide a form for taking into account the rights of the future. Even with the most open and public debate, there is no voice that can speak for the concern of future generations, their desires, or their evaluation of good and harm. The only principles that can be used for bringing the future into our decisions are moral and ethical ones, and even these are difficult to apply. One suggestion for this purpose is the extension of two ethical principles usually defined in a more limited context. The first is to provide the fullest information possible as to future risks and costs (Ref. 5). That the future may not be able to act upon this information does not remove our obligation to supply it. A minimum ethical principle for exporting risks is to do so openly. The second principle is to act so as to minimize irreparable harm. Every action has consequences for the future. As Hannah Arendt has pointed out (Ref. 6), this distinguishes actions taken in the context of human plurality from those actions that deny it. We do not have to draw back from taking action; however, we must accept responsibility for the consequences.

These principles have led to the suggestion that primacy must be given to minimization of long-term risks in establishing a framework for organizing waste management options. Immediate and short-term risks and costs will be borne by the generation that derives the benefits, and their descendants. Risk and benefit can be weighed and decisions made fairly, as the risk cannot be exported to other populations or the future. Costs are the least important. They are unlikely to be prohibitive, and can be used to select options that are acceptable on other grounds. If society decides it cannot or will not pay for the best system it can devise, this decision will at least be made openly.

The United States is currently engaged in attempting to determine the technical options for and the goals of waste management policy. Once these are defined, criteria can be established, based on empirical data, to provide a quantitative basis for choice. In the usual circumstances, these criteria would then be translated into standards, such as allowable releases in Ci/year, that are based on normative judgments as to relative risk and benefit to society.

Unfortunately, even if there were general agreement on the basis for protecting the future, this would not necessarily lead to the selection of appropriate waste management standards. However, it might lead to the rejection of some inappropriate ones. Zero release - zero dose, for instance, sounds impressive. Given our uncertainties abut long-term institutional and geologic stability, however, can it ever be more than an idealistic phrase? Can it take into account anthropogenic intrusion? Such problems do not vanish if a specific low, but nonzero, release rate is used.

I believe that regulatory action will have to be based on criteria for disposal practices and sites, rather than standards for release or dose. These criteria may in themselves not be wholly adequate or easy to define, and may involve much uncertainty, but to fall back on the goals themselves would lead to no program at all. There must be some interpretation of the goals into operational specifications if judgments are to be made.

A general goal, for instance, is the interposition of barriers between nuclear wastes and living things. These barriers can be physical, such as geological emplacement; technical, such as vitrification to prevent leaching; or institutional, such as a monitoring and repair team. In listing them in this order, the author has deliberately performed a ranking that reflects not only his own judgment as to the order of importance, but also correlates with the time scales previously defined. Geology can, if carefully chosen, provide a secure and not too uncertain barrier over very long times. Low leach rate appears to be reliably predictable over hundreds of years but, for glass at least, is less sure over longer periods of time. Institutions are to be used for error correction and detection, and are not relied upon to provide a secure barrier. If institutions were reliable and long-lived; if their performance and objectives were stable over time; if we knew how a waste management institution would respond to changes in the scale of operations, to public confidence, and to the defined importance of its tasks, then we might begin to consider institutional solutions adequate for the intermediate term. In that case, a very retrievable surface storage facility would be acceptable. Error detection and correction, monitoring, and future alterations in disposal method would all be facilitated. But even under the most stringent assumptions as to future stability, there is no ethical justification for imposing upon the future an obligation to take care of our wastes for no benefit, a responsibility to maintain their institutions at a level of stability and performance that we define, in order to protect themselves from the consequences of our actions (Ref. 7).

Technical barriers should not be relied upon for primary containment. There are limitations to our technical knowledge, many of them as yet unperceived. The behavior of some materials, such as concrete or glass, over many thousands of years under the conditions of thermal and mechanical stress that may be encountered, may be accurately modeled by short-term experiments. However, we have no way of knowing for sure without a verified physical theory for their behavior. More importantly, reliance upon technical barriers alone implies accessibility. As with institutional barriers, this provides the ability to repair or replace a system that shows signs of failure. However, without even attempting to judge whether future beings will be more or less technically competent or intelligent than ourselves, or whether they will be able to detect or understand a release of radiation, the burden of keeping the site free from intrusion and providing for monitoring and repair will be transferred to them for no benefit. If institutions or information should disappear, such a method might prove to be an "attractive nuisance"--drawing uninformed but intelligent beings to it by the inexorable force of intelligent curiosity.

Therefore, I argue for placing primary reliance on physical barriers such as deep geologic implantation. These are the most secure against uncertainty and natural accident. If properly chosen, away from mineral deposits and features that draw the interest of scientists or mineral explorers, they can also be fairly secure against anthropogenic intrusion.

Recently, the author advanced two social criteria--technical irreversibility and multiplicity--that attempted to address a mixture of natural and anthropogenic causes of failure (Ref. 8). They were constructed specifically to address the reduction of future risk in the face of inherent uncertainty as to social and political developments over required isolation times, and to provide for safe disposal without requirements for future ability to recognize, repair, or detect errors or failures. Technical irreversibility is defined by a combination of social and physical elements that measure both the size and the sophistication of the technology or natural mechanism that would be necessary to return the wastes to the biosphere in quantities that would be harmful to life. It is intended to correlate with the degree of scientific or technical aptitude that would be required for deliberate waste recovery by a society of intelligent beings, and with the size and cost of the required effort.

Technical irreversibility measures resistance to both social and physical intervention. It does not correlate precisely with scientifically defined irreversibility. Irreversibility can be expressed mechanically, as with a ball rolling down a hill set in the middle of a flat plain. The application of a little intelligence and energy can easily restore the ball to the top of the hill. The irreversibility embodied in the second law of thermodynamics is based on the difficulty in restoring an initial situation in the face of statistical improbabilities, and the unlikelihood that a specified event or set of conditions will spontaneously occur if it is but one of a large number of accessible outcomes. The presence of intelligence, however, allows the creation of improbable circumstances; reversibility may be expensive, but it is not in principle impossible.

There are parallel examples of social irreversibility. An example of almost purely social irreversibility is the fabulous pirate practice of burying a treasure in a remote or obscure location and then killing those who know of it. Mechanically, the burial is very reversible; retrieving the treasure is simple once its location is known. However, it is socially irreversible, since accidental discovery is highly unlikely and a deliberate, but unguided, search has a very low probability of success.

Multiplicity is defined in two ways. Site multiplicity is intended to provide security against site-specific failures, providing some degree of damage limitation. Diversity of option is intended to provide security against generic failures. Although not much actual damage limitation could be provided by only having a few options available, it would be valuable to have alternates in operation if one of the methods should suffer from a generic problem that rendered it unsuitable.

Taken together, I suggested that these criteria could be used to screen waste management options according to the degree of security against natural and social intervention to provide for a minimum acceptance level for irreversibility. In that paper (Ref. 8) it was also suggested that complete irreversibility may not be desirable, in that it precludes options for the future (Ref. 9). Future generations may desire to recover our wastes as a resource, or to remove and reemplace them in a more secure manner. If the wastes were not emplaced more irreversibly than present ores, a technically and scientifically advanced future could recover them. Yet, in the absence of adequate technical sophistication and information, they would remain safely out of reach.

It must be emphasized that, in the author's view, there is no simple dichotomy between storage and disposal, but rather a continuum stretching from retrievable surface storage to irrecoverable disposal. With all humility as to my ability to predict the future, I believe that engineered storage can be provided over the short and intermediate term in such a way that the wastes are recoverable at costs that are not prohibitive, yet, should institutions fail, the site will revert itself to a secure and acceptable method of ultimate disposal.

If, for instance, mining were required, recovery from the site would be more costly than it would for purely retrievable methods. However, we can and do mine uranium ores at concentrations of only 0.2 percent, and are prepared to mine even poorer grades. Information as to site location can be provided in such a way that it will not be accessible to those incapable of understanding the risks involved. One suggestion is to tag the sites or containers with a low-level radioactive source. Such provisions may be difficult; however, they are not impossible.

In view of the broad scope of this Workshop, I believe a word needs to be said about the uniqueness of the mill tailings problem. Other types of radioactive waste can be dealt with in a manner similar to the high-level wastes, at least generically. Criteria such as irreversibility are generally applicable, and only need to be modified according to the lifetime and toxicity of the waste in question.

Mill tailings, however, cannot be compacted. There appears to be little possibility of their emplacement in repositories. The primary hazardous chain is the decay series of thorium-230, which contains as its first decay product radium-226, an alpha-emitter that is soluble in water and readily taken up through the intestine. Since the half-life of thorium-230 is about 76,000 years, this problem is even longer term than that of the plutonium series in high-level wastes. Radon-222, the daughter of radium-226 is a radioactive noble gas with a 3.8-day half-life that diffuses out through the pile and is spread on the wind. As it decays, it may deposit its alpha-emitting daughters, particularly polonium-210, on plant life and buildings (Ref. 10).

How are these tailings to be included within the framework of criteria for disposal of other wastes? Shall they be dumped in the oceans or dispersed? This is highly irreversible and very multiple but guarantees a maximum dose commitment. If they are to be buried or covered over with asphalt or dirt, what provision can be made against the type of anthropogenic actions that led to houses being built on foundations made with tailings in Grand Junction, Colorado? How are we to balance the distributed but certain dose commitment of dispersal, against the possible dose limitation of burial with the attendant risk of concentrated exposure? It is not clear what the basis for judging methods of mill tailings management should be, or what the implications are of giving them criteria that differ from those accorded other wastes. It is clear, however, that the criteria will have to differ. Unfortunately this points out the limitation on our intention to apply ethical standards uniformly.

To summarize, the author can offer no suggestion as to how to convert this melange of criteria into a simple and uniform set, let alone convert them into standards. Several of the criteria appear to be generally usable--the absence of water, seismic stability, irreversibility, and others that have not been discussed in this paper. Any disposal method chosen will undoubtedly have other criteria specific to the type of waste or the operational conditions.

The author cannot envision boiling these criteria down to a set of simple standards for release rate and dose commitment without trivializing both the criteria and the ethical basis for their establishment. Using criteria that evaluate performance and design of specific sites is not so simple as establishing a set of numerical standards. However, in the face of uncertainty, simplicity may be more a vice than a virtue.

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THE LEGACY QUESTION

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The management of nuclear wastes is a major issue in the possible use of nuclear energy to aid in alleviating our present energy situation. The transuranics, in particular, are a focus of attention because of their long half-lives and the concomitant need to control them for thousands of years--a period unthinkable to most of us. There appears to be an implicit assumption among many, that such disposal means assured containment until the isotopes have decayed. This is a task that the engineer designing the disposal site will find extremely difficult to fulfill and may require the expenditure of resources that could be used to fill other needs. In this paper, I will recommend that a priority need in the management of very long-lived wastes is a criterion that will set forth the proper concern for both future risk and present needs. With such a criterion, the engineer can assess the suitability of various proposals and provide a rational design. Without it, he is left to his own judgment and the inevitable second-guessing and tug-of-war between differing views that have plagued, not only nuclear energy, but other industries in this country.

The broad objectives for nuclear waste disposal, as for other potentially hazardous wastes, are to place the unwanted materials in a position where they are safe, but by a method that does not impose an excessive burden on the resources that are so imperative for other needs. Once again we are faced with the problem of defining "safe"; however, this time in the context of the long time periods for which many of the radioactive species will survive. I would note in passing that this problem is not unique to radioactive materials but must also be considered for the stable chemical wastes, particularly the toxic metals that cannot be degraded to less toxic or nontoxic forms. Thus, the considerations from this workshop and the resulting criteria from the EPA should be considered as applicable, in a large degree, to these other materials. It is my feeling that we should keep this broader potential application in mind as we discuss these issues, and I would hope that any criteria would be derived in cooperation with the EPA people working on other hazardous wastes.

The legacy question in my title refers to the definition of appropriate actions in this generation to provide a world that will allow future generations to use the earth without excessive limitations cause by our use and disposal of potentially hazardous materials. While this question is, on the surface, deceptively simple, there are many ramifications that must be

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explored. For example, if our concern is with mankind, our first and foremost obligation is to survive so that there will be future generations. Not only must we survive, many of us feel that we should preserve and extend many of the amenities and present technologies that extend both our span of life and quality of life. Thus, at the very beginning there is conflict between preserving the environment in its present form and providing the wherewithal to survive and extend that which we want to leave. The present cold winter heightens our appreciation for the need to take action on the energy supplies that we all depend on for survival.

We do have a starting point for our deliberations in the Declaration of National Environmental Policy from the National Environmental Policy Act of 1969. This states that it is the policy of both governmental and private organizations "to use all practicable means and measures...in a manner calculated to foster and promote the general welfare, to create and maintain conditions under which man and nature can exist in productive harmony, and fulfill the social, economic, and other requirements of present and future generations of Americans." The act then specifies that all practicable means consistent with other considerations of national policy shall be used so that the Nation may "fulfill the responsibilities of each generation as trustee of the environment for succeeding generations."

These statements outline the general policy in a manner that should be acceptable to most people. However, as is common with many policy statements, it is very general and it is the job of this workshop to provide input that will allow more specific criteria to be developed that will meet the general policy in regard to trusteeship of the future in relation to the present needs and policies. The remainder of this paper discusses a few of the points that I feel should be considered in establishing a criterion.

There does seem to be agreement among those studying the problem that containment for the next several hundred years or even longer can be obtained by several of the methods now being considered. However, the more distant future is a different question. We know from past history that changes in the climate have led to ice ages, and the courses of rivers and positions of lakes have changed. Thus, we can expect future changes that will have impact not only on the disposal site, but will bring about drastic changes in population distributions and, perhaps, the character of the civilization. A requirement to provide facilities that will have the continued assurance against risk in the time-period that we will require for the next several hundred years is not only difficult, but in the long run, may be counterproductive because of our expenditure of present resources to protect against unknown conditions in the future.

To further illustrate the problems of setting policy for the future, let me introduce several scenarios as to the future of civilization. These are very general and lacking in detail but they will illustrate the problem.

1. In the most optimistic view of the majority of the public we will continue to develop both technology and social knowledge so that the future generations will have access to living conditions and controls far beyond anything we could imagine. For example, if this scenario is fulfilled, then the probability of effective treatments for the biggest risk from radiation--cancer--appears to me to be a realizable achievement within the next hundred years or so.
2. A scenario that appears to guide many of us in our decisions is that the status quo will be maintained; that is, that our social institutions and technology will remain as they are now with only minor perturbations. In my opinion, this is a very unlikely course since most static systems of any complexity eventually regress.
3. The current civilization regresses to a point where modern medicine, public health, transportation, and agriculture are no longer available. The degree of regression depends upon the cause, but to the extreme, could be to a primitive, village society. A number of causes could be expounded but it is noted here than one could well be a shortage of energy to grow food and to tie the governmental institutions together. Of course, an alternate extreme would be the complete elimination of the human species with another species starting the long road to civilization.
4. In the final scenario, the human race is destroyed by a natural or man-made cataclysm and no new species replaces him.

We do not know which of these the future will bring but it is important that we attempt to minimize the probability of the last two by making wise use of all of our resources, including nuclear energy, and not setting such excessively stringent criteria that we forego the use of any of our resources.

In conclusion, I would like to urge a criterion as to acceptable risk in the future, including the distant future, sufficiently well defined that it can be used by the engineers in design of facilities. I recognize the difficulty in obtaining a consensus among the many viewpoints in the country, but believe that a wise resolution of this question will be beneficial in conserving our vitally needed rsources of coal and hydrocarbons so necessary in the near future for medicinals, mobile fuels, and fertilizers.

LONG-TERM IMPLICATIONS OF RADIOACTIVE WASTE MANAGEMENT: SUMMARY AND CONCLUSIONS OF WORKING GROUP 3

LONG-TERM IMPLICATIONS OF RADIOACTIVE WASTES

The topic of Working Group 3 was "Long-Term Implications of Radioactive Waste Management." Thirty people participated in the discussions. The affiliation in the group included government employees, industry representatives and consultants, public interest groups and citizens representing themselves. This variety of affiliations enabled the group to consider a wide spectrum of viewpoints in their deliberations.

The following consensus opinions were developed by the group and are presented to summarize our principal conclusions.

1. We should get on with the process of developing criteria for radioactive waste disposal.

   It was the feeling of the group that the criteria are needed now so that those groups involved in the design of facilities and their regulation can proceed with their work without delay. Further, it was felt that current technology is now adequate for this effort to go forward.

2. Waste disposal risks and benefits, both calculated and perceived, should be factors in the development of criteria.

   "Perceived" risks and benefits were defined as those which the public, by fact of their own knowledge, experience, or beliefs, view as real. People may believe in risks which do not exist, but they may also recognize risks which regulators have overlooked. In addition, the calculation of risk is inexact and thus it should be tempered by judgment.

3. Criteria should take into account impacts on the international community.

   It was felt by the group that the need for such a consideration in the development of criteria was fairly obvious and little discussion was necessary to reach a consensus on this opinion.

4. The public, and state and local governments should be involved in the decision-making process.

   Several examples where a lack of public involvement created problems of public acceptance were discussed in the group. Included in these examples were the Windscale

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accident, the proposed Lyons, Kansas, depository, and the proposed Michigan core drilling. All were characterized by oversights on the part of scientists and/or regulators which created problems of public acceptance. Accordingly, the decision-making process should be open in fact as well as in appearance.

5. The criteria should take into account the fact that radioactive waste disposal solutions should be independent of the stability of societal institutions.

   It was assumed that institutional controls would remain in effect until the repository was sealed. At this point, reliance should no longer be placed on institutions. Concerns of the groups ranged from the possibility of accidental or purposeful intrusion into a repository to the failure of institutions to carry out necessary surveillance.

6. It seems reasonable to assume that there exist suitable geological formations which will remain stable for the period of concern in the disposal of radioactive wastes.

   Various viewpoints were considered in the development of the consensus. These viewpoints included:

   a. That we could probably identify suitable formations, although no consensus of a suitable depth or a final waste form was reached.
   b. That the problem of high-level wastes was primarily a 1,000-year problem and thereafter the average concentration of the transuranics is similar to pitchblende although there is still the possibility of "hot spots" or small areas of high activity.
   c. That the term "geological stability" implies isolation from the biosphere for the period of concern.

7. Risks to future generations must be included in the development of criteria.

   The working group felt that the following order represents a ranking of the priorities that should be used in establishing criteria: (1) minimizing long-term risks, (2) minimizing short-term risks, and (3) minimizing costs.

   Viewpoints expressed in the development of this consensus include:

   a. In any reasonable management scheme risks to present and future generations are so small, relatively and absolutely, as to be negligible.
   b. Zero release and zero dose were discussed. It was felt that this is a desirable goal. However, it was also felt that the word "zero" should not appear in a criterion.

    c. It is possible to trade-off future versus present risks. Plutonium recycling and transmutation were cited as examples of such a possible trade-off.
    d. Some members of the group felt cost was less important than technical considerations of the integrity of the repository.
    e. Some risks have to be borne to accrue benefits.

8. If feasible, options should be left open for future generations to improve upon our program of waste management. However, in doing this, safety should not be compromised.

   Viewpoints expressed in the group on this consensus incude:

    a. This is a moot point; that is, if we make waste in any way retrievable, we compromise safety.
    b. Options for change will be available until the repository is closed.
    c. Costs are important and cannot be ignored.
    d. Repositories should not be located in areas where minerals or resources are likely to be found.

9. Both the form of the radioactive waste and method of disposal need to be considered in the establishment of radioactive waste management criteria. But the criteria should certainly not be keyed to any single waste form or disposal method.

   Several viewpoints were expressed in the development of this consensus:

    a. Wastes should be categorized on the basis of toxicity and concentration. Other criteria such as solubility, depth of burial, requirements for geological stability, and possibly others should be applied to each category of waste.
    b. It will be difficult to meaningfully address all waste forms with a single set of generic criteria.
    c. Criteria should not be limited by current technology and should specify performance goals rather than disposal methods.

10. Other opinions presented but not discussed fully included:

    a. Any criteria which are developed need to be reviewed periodically in the light of developing technologies.
    b. Future generations should be informed to the extent possible of the risks passed on by present generations.
    c. Toxic wastes should be examined in the same context as radioactive wastes.

d. Consideration of the risks of management of any combination of type of waste and disposal technique should also include the transportation risks.

e. It was also noted that wastes arising out of decommissioning nuclear facilities are considered another waste form.

Our discussions focused on geological disposal of high-level wastes. We recommend that in the next Workshop more consideration be given to the safe disposal of other radioactive wastes.

RESPONSE OF WORKSHOP PARTICIPANTS TO SUMMARY AND CONCLUSIONS OF WORKING GROUP 3

Second Plenary Workshop Session

JAMES E. MARTIN (Environmental Protection Agency, Washington, D.C.): The moderator for Group 3 is Susan Lepow from the Environmental Protection Agency in Washington, D.C.

SUSAN LEPOW: I would first list to introduce the panel for Working Group 3: Chauncey Kepford, from the Environmental Coalition on Nuclear Power, State College, Pennsylvania; Evan Vineberg, from the Environmental Protection Agency in Washington, D.C.; Robert Schainker, from Systems Control Inc., Palo Alto, California; Robert Shoup, from Union Carbide, Oak Ridge, Tennessee; Jerry Swift, from the Environmental Protection Agency, Washington, D.C.; and G. Hoyt Whipple, from the University of Michigan in Ann Arbor, Michigan. The first question is from William Lochstet, "Should or will future generations be expected or required to monitor for leaks?"

EVAN VINEBERG: Considering the primary issue, high-level wastes, I think it was the consensus of the group that once the wastes were put in the ground they should stay there and be kept from the biosphere. I think that was the goal we were all working for.

WILLIAM A. LOCHSTET (Environmental Coalition on Nuclear Power, Julian, Pennsylvania): The question is, you expect it to stay there but do you keep checking to make sure that it does? I mean that is what you would do when you go looking, and you hope you do not find anything.

VINEBERG: I think the answer is no, because we are not anticipating societies to be able to look after these wastes indefinitely and I do not think we can therefore expect them to be able to monitor them. That is why we want them to stay there once they are put there.

JERRY SWIFT: I think this point itself was not directly addressed but our point of view was that the design should be such that no release would be expected and that there should be no demand for institutional surveillance of the repositories. Naturally we would expect some surveillance as long as the Nuclear Regulatory Commission continues to regulate.

LEPOW: Next comment from Stanley Logan, University of New Mexico. To aid in public understanding of the proceedings, it is recommended that a glossary of terms be included. A glossary was included in the "Issues & Objectives Statement." Missing terms such as "fault tree," "dose," "rem," etc. should be added. I suggest reviewing the texts for other terms that should be included for clarity.

Don Williams, page 3-44, question 7. Let the record state that there is disagreement with the ranking of priorities indicated, namely, long-term, short-term, cost savings. I would propose short-term, cost, long-term. Would you like to add anything to that comment?

DON WILLIAMS (Battelle, Pacific Northwest Laboratories, Richland, Washington): I guess I will elaborate a little bit. My concern is that I do not agree with the priority that somebody else has made. My personal opinion is that self-preservation is the first law of nature and I would like to see that extended in the criteria.

VINEBERG: One immediate comment that comes to my mind is that it is very difficult to quantify in dollar terms what one means by self-preservation.

PANELIST: For the record I would like to indicate that the working group on this whole panel did discuss the factors that you just mentioned, the survival issues being primary, but the general concensus of the entire panel was the order that we indicated. I just wanted to make sure that after due discussion of the point you considered, that we did rank them in the order presented.

SWIFT: Also a view was presented that survival of the species is sometimes given more consideration than self-preservation.

PANELIST: I participated in the deliberations of Group 3 and I think some of us felt that it does not really make any difference which priority you put first because if you put priority on either one of them, you automatically are taking care of the other. By giving long-term priority you certainly have protected yourself.

LEPOW: I think that is a fair representation of the Group. The next question is from Ed Toombs. What is "irretrievable"?

A. E. TOOMBS (Stone & Webster Engineering Corp., Bethesda, Maryland): That is in reference to the statement on page 3-4, item 8a. There you say that this is a moot point, that if we make waste in any way retrievable, we compromise safety. It appears that when we are talking of retrievability we are going toward the absolute again. I am not sure that we can make anything absolutely irretrievable by keeping it intact and burying it in a geological formation. Would anyone care to comment?

PANELIST: I think basically we agree with that. You never obtain absolute irretrievability but you want to go to a point where you maximize your isolation, which is contradictory to having some type of retrievability. In other words we want to make it as difficult as possible for some future generation to have any reason to go back in there by selecting a site that is unattractive as far as resources and make the waste form as unattractive as possible.

LEPOW: And the last question is from William Remini (Energy Research & Development Administration, Washington, D.C.) Was there any discussion as to the magnitude of the possible costs in carrying out your recommendation. And if so, who should carry the burden of supplying these funds?

SWIFT: I think the opinion was expressed that the cost of the proposed technologies all appeared to be within reason.

G. HOYT WHIPPLE: I concur with the statement that has just been made and the answer to who pays, which was part of your question--I am presenting no consensus when I give this answer, it is my own opinion--all I can think of is to paraphrase Mr. Truman's comment and reverse it--the buck starts here. Why quibble? Whether it is industry, government, or the ratepayer, _we_ pay it. I do not see that anything is gained by discussing that; perhaps you meant something more than I see in your question.

LEPOW: If there are no further comments, we are finished. Thank you.

WORKING GROUP 3 EXECUTIVE COMMITTEE

LONG-TERM IMPLICATIONS OF RADIOACTIVE WASTES

NAME	AFFILIATION
Chauncey Kepford†	Environmental Coalition on Nuclear Power
Susan Lepow*	Environmental Protection Agency
Thomas W. Philbin	Ecological Analysts, Inc.
Evan Vineberg†	Environmental Protection Agency
Robert B. Schainker†	Systems Control, Inc.
Robert Shoup†	Union Carbide Corp.
Jerry Swift†	Environmental Protection Agency
G. Hoyt Whipple†	University of Michigan School of Public Health

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* Moderator.

† Panelists for the Plenary Workshop Session, 5 February, 1977.

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PREPARED STATEMENTS FROM THE PUBLIC

STATEMENT BY BRUCE ROSENTHAL*

Radioactive wastes from uranium mining and the atomic reactor fuel cycle are becoming an increasingly large blemish for the pro-atomic establishment. Senator John Pastore, chairman of the Joint Congressional Committee on Atomic Energy and a staunch nuclear advocate, says, "The most important problem facing nuclear power is waste management."

Not only have the government, the utilities, and the atomic industry spent vast sums of money and been unable to devise a permanent means of storage for these wastes, but many of the storage sites are also leaking like sieves, emitting radioactive particles. And the U.S. Court of Appeals has recently chastised the Nuclear Regulatory Commission (NRC) for failure to adequately consider the problems of wastes in licensing nuclear plants.

CRITICAL MASS has highlighted instances of radioactive emissions from the remains (tailings) at uranium mining and waste storage areas (see CM Oct. 1975, p. 3; Feb. 1976, p. 1; May 1976 p. 30), but similar occurrences have become more prevalent in recent months. For example:

--In June 1976 workers wearing protective jumpsuits and using respirators began a yearlong task of removing 400 cubic yards of radioactive dirt contaminated by plutonium at the Rocky Flats (Colo.) nuclear weapons plant. The contamination was caused by corrosion in 55-gallon metal drums used in the storage field. The yearlong effort will be necessary to clear an area the size of an average living room. The dirt will now be shipped to Idaho for storage in another form.

--A park in Chicago was closed in July 1976 as a result of apparent dumping of radioactive materials there in the 1930s and 1940s by the now defunct Light and Chemical Co. The 100-acre Reed-Kempler Park has been closed for further testing. The NRC discovered the abnormally high radiation levels as the result of an anonymous telephone call to a newspaper reporter.

--Traces of radioactive substances were recently discovered in the ocean 120 miles east of Ocean City, Maryland, a prime tourist and vacation area. Traces of plutonium were found 40 miles from San Francisco near the Farallon Islands in another underwater waste disposal site. The area is inhabited by sablefish, which are sold commercially by fishermen.

--Leaks of radioactive wastes at the Turkey Point atomic reactor near Miami, Fla. exemplify many of the problems surrounding waste storage. Although leaks were known to exist in the storage pits in 1972 before the reactor began operations, Florida Power and Light considered the problem "minor" and made no repairs. Today, water that surrounds the radioactive wastes has itself become contaminated and is leaking from the storage area at the rate of 90 gallons per hour.

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* Taken from: Rosenthal, Bruce. 1976. Radioactive waste disposal problems mount. Critical Mass 2:5.

Attempts to repair the leaks have not been successful thus far, partly due to the high concentration of radioactivity in the area. And since permanent storage sites and waste reprocessing facilities have not been developed in the United States, even though 58 power plants are operating, the radioactive wastes cannot be emptied from the storage tanks so that the leaks can be repaired.

STORAGE AT SEA

In the early days of this country's atomic program, offshore sites were used to dispose of radioactive wastes. Beginning in 1946, more than 28,000 55-gallon drums were dumped into the Atlantic and 47,000 into the Pacific Ocean as a result of the government's atomic weapons and research programs.

The Environmental Protection Agency (EPA) is currently searching for these drums in an attempt to develop "effective controls on any ocean dumping of low-level radioactive wastes, and in order to assess the effectiveness of past packaging techniques," according to Robert S. Dyer of the EPA's radiation office. One of the problems facing the EPA effort is that it is not certain where the drums were dumped. Although the dump sites are designated in the records, apparently a minimal effort was made to use the specified sites. The EPA investigation has thus far discovered the radioactive releases near Ocean City, Md. and the Farallon Islands in California.

STORAGE ON LAND

Attempts to find suitable land storage of radioactive substances have taken several forms. Some of the radioactive remains from uranium mining - uranium tailings - have been stored at 21 sites in the west. In other areas, the tailings have been neglected by officials and used by contractors as land fill or have been washed away by erosion or rain water. The EPA and the NRC are presently investigating the extent of the contamination and the possible solutions from these careless activities (see accompanying list).

Wastes from the reactor fuel cycle are often stored in pools of water on site due to the lack of sufficient permanent storage facilities and reprocessing systems.

Some temporary storage facilities have been constructed for waste disposal. Some of these 19 sites are for high-level wastes and some are for low-level wastes (see accompanying list).

Another aspect of the controversy revolves around the question of how to prevent future generations --- perhaps thousands of years from now --- from accidentally stumbling across underground atomic waste vaults. Carl Kuhlman, an Energy Research and Development Administration nuclear waste official, suggests constructing monuments over waste sites to warn unsuspecting persons. Professor George Kistiakowsky, former science advisor to President Eisenhower, counters that over a period of many thousands of years, "the English language probably would disappear" and an ice age "would smash all monuments."

COURT DECISION

The NRC has contended that when approving new atomic reactors, the issue of waste disposal need not be considered. A U.S. Court of Appeals court in Washington, D.C. on July 21 ordered the NRC to consider waste disposal in future decisions.

The court ruling was in response to a Natural Resources Defense Council suit against the NRC in connection with the Vermont Yankee atomic reactor. (A similar ruling in a separate case ordered the NRC to consider energy conservation aspects when approving reactors.)

In the waste disposal case, U.S. Circuit Chief Judge David L. Bazelon said: "Not only were the generalities relied on in this case not subject to rigorous probing - in any form - but when apparently substantial criticisms were brought to the commission's attention, it simply ignored them, or brushed them aside without answer."

CONGRESSIONAL OVERVIEW

Members of Congress are becoming skeptical of the waste disposal situation. Although there have been repeated assurances for decades that government and industry could resolve the waste disposal dilemma, a report released on June 30, 1976 by the Subcommittee on Conservation, Energy and Natural Resources Subcommittee of the House Committee on Government Operations points out that "progress toward resolution of this problem has been sketchy."

The report, entitled "Low-Level Nuclear Waste Disposal" is based on hearings and an investigation conducted by Subcommittee chairman Rep. Leo J. Ryan (D-CA). In view of the fact that "some of these (storage) sites are now releasing radioactivity to the environment, in some instances only 10 years following their selection as facilities designed for the containment of radioactivity for hundreds of years," the subcommittee contends that the problem should "be considered in all its gravity."

As the Federal government and the atomic industry continue their search for a safe, reliable disposal method for radioactive wastes, the Subcommittee reports that Federal officials estimate the volume of wastes which will need to be stored by the year 2000 will cover a four-lane highway, one foot deep, coast to coast. Much of this waste would be low level and therefore less concentrated than high-level wastes on a unit-by-unit basis, but low-level wastes are just as dangerous as high-level wastes. Also, low-level wastes cannot be reprocessed --- they must be stored.

Radioactive Storage Sites: Where Are They?

1. Low-level wastes stored at Hanford, Wash. (stored on-site at operating atomic reactors)
2. Inactive uranium mill site at Lakeview, Oreg.
3. Low-level waste at Lawrence-Livermore Lab, Livermore, Calif.
4. Inactive uranium mill site at Lowman, Idaho

5/6. High and low-level wastes stored at Idaho National Engineering

7. Low-level wastes stored at the Nevada Test Site
8. Inactive uranium mill site at Salt Lake City, Utah
9. Inactive uranium mill site at Green River, Utah
10. Inactive uranium mill site at Mexican Hat, Utah
11. Inactive uranium mill site at Monument Valley, Ariz.
12. Inactive uranium mill site at Tuba City, Ariz.
13. Inactive uranium mill site at Converse County, Spook, Wyo.
14. Inactive uranium mill site at Maybell, Colo.
15. Two inactive uranium mill sites at Rifle, Colo.
16. Inactive uranium mill site at Grand Junction, Colo.
17. Inactive uranium mill site at Naturita, Colo.
18. Inactive uranium mill site at Gunnison, Colo.
19. Inactive uranium mill site at Durango, Colo.
20. Two inactive uranium mill sites at Slick Rock, Colo.
21. Inactive uranium mill site at Shiprock, N.Mex.
22. Inactive uranium mill site at Ambrosia Lake, N.Mex.
23. Low-level waste storage at Los Alamos Scientific Laboratory, Los Alamos, N.Mex.
24. Low-level waste storage at Sandia, N.Mex.
25. Low-level Waste Storage at PANTEX, Amarillo, Tex.
26. Inactive uranium mill site at Ray Point, Tex.
27. Inactive uranium mill site at Falls City, Tex.
28. Low level waste storage at Paducah, Ky.
29. Low-level waste storage at Oak Ridge National Laboratory, Oak Ridge, Tenn.
30. Low-level waste storage at Oak Ridge Gaseous Diffusion Plant, Oak Ridge, Tenn.
31. Low-level waste storage at Y-12, uranium enrichment building near Oak Ridge, Tenn.
32. High and low-level waste storage at Savannah River Plant, Savannah River, Ga.
33. Low-level waste storage at Fernald, Ohio (Feed Materials Plant)
34. Low-level waste storage at Portsmouth, Ohio
35. High-level ERDA waste storage at Richland, Wash. Low-level commercial waste storage by Nuclear Engineering Co. at Richland, Wash.
36. Low-level solid waste storage at Beatty , Nev. by Nuclear Engineering Co.
37. Low-level solid waste storage at Sheffield, Ill. by Nuclear Engineering Co.
38. Low-level solid waste storage at Morehead, Ky. by Nuclear Engineering Co.
39. Low-level solid waste storage at West Valley, N.Y. by Nuclear Fuel Services
40. Low-level solid waste storage at Barnwell, S.C. by Chem-Nuclear Services, Inc.

STATEMENT BY FREDERICK FORSCHER*

Nuclear Waste Management is a complex social-economic-technical subject. There seems to be general agreement that a public policy should ensure exclusion of radioactive waste from the biosphere, effectively, for long times and below acceptable risks. There is, however, no consensus on what constitutes effective, long times and levels of acceptable risks. To reach consensus on these issues requires structured and informed public participation, such as is employed in the formulation of criteria and standards by the voluntary standards movement, utilizing ANSI's procedures. Political reality requires the active participation of the public in the decision-making process. The trend in this direction has become quite clear during the October 1976 meeting in Chicago, on Nuclear Waste Management, and is being carried forward by EPA's workshop on Radioactive Waste Management in Reston (February 1977).

I am proposing to address primarily the process of arriving at criteria and standards, so that the substance of the resulting document represents the best interdisciplinary consensus. I am proposing to employ the time-tested method of developing consensus type technical standards. This process cannot be done "in-house" at the NRC, nor at any other governmental agency. No single organization, private or public, industrial or academic, has the know-it-all competence to develop criteria and standards that require complex trade-offs (judgments) in social-economic-technical matters.

A National Academy of Science panel found recently, that in order to ensure effective waste management, the Federal government must exert strong leadership in assigning authority for setting and implementing standards, and ensuring coordination between Federal, state, and local agencies and private industry.

The process of developing a consensus type technical document can be divided into three consecutive steps:

1. Develop the scope and, if necessary, definitions and time frames.
2. Select and recruit a representative (interdisciplinary) writing group of about 7 to 13 specialists.
3. Schedule and chair the necessary committee meetings.

Criteria and standards will play an increasingly important role in the development of a regulatory framework for nuclear waste management. The ANSI process allows judgmental and interdisciplinary input on a timely basis.

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* Energy management consultant.

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STATEMENT OF PACIFIC LEGAL FOUNDATION*

Pacific Legal Foundation (PLF) submits the following statement concerning the proposal by the United States Environmental Protection Agency (EPA) to develop environmental radiation protection criteria and standards for radioactive waste (41 Fed. Reg. 53363 [December 6, 1976], 42 Fed. Reg. 2331 [January 11, 1977]). Pacific Legal Foundation, a nonprofit, public interest legal corporation, seeks to provide a balance of interests in administrative and judicial proceedings involving environmental controls, land use, national defense, and government regulations.

In this matter of developing environmental radiation protection standards and criteria for radioactive waste, PLF has certain concerns. First, no standards or criteria should be promulgated that would severely restrict the development of U.S. nuclear power and its beneficial applications. Second, criteria and standards adopted should be promulgated only after a careful examination of the risks and benefits to society and the impact such a proposed program would have on these factors. Third, PLF believes that the activity proposed by EPA is not within that Agency's statutory authority. It is a duplication of similar programs being developed by the Energy Research and Development Administration (ERDA) and the Nuclear Regulatory Commission (NRC).

Finally, for these workshops to be truly effective they must be conducted in an objective atmosphere without the usual rampant emotionalism that has all too frequently surrounded discussions about nuclear power. In the words of a recent columnist, "Hysteria about the very notion of domestic development of nuclear power has blocked out all rational discussion of the need for and the feasibility of safeguards. Agitation has supplanted engineering."†

Any standards developed to regulate the disposal of radioactive wastes must be realistic and not unduly restrictive upon the development of nuclear power in the United States. The importance of this statement is underscored by the present dependence of our economy on petroleum, and more specifically its growing dependence on foreign sources of petroleum.

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† Janeway. "On Nuclear Front, Russia is Realistic," _Washington Star_, Jan. 23, 1977, at E-1, E-12.

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The development of alternate energy sources to the point of large-scale commercial applications will take several decades, as a result of which this nation will continue to rely upon both its own fossil fuel resources and uranium fuel.* In this context inflexible and unrealistic regulations would render the use of nuclear power, one of the safer forms of energy, either impossible or economically infeasible and discourage industry from further development of this source of energy. Moreover, regulations that would lead to delays in the uses of nuclear power will cost society substantially.†

The development of criteria and standards for dealing with radioactive wastes will obviously have a substantial impact on the utilization of nuclear power and its development. A Federal agency entrusted with such a task has an affirmative duty to analyze the broad public interest affected by the proposed regulations. This analysis cannot be conducted in a vacuum; at a minimum it requires a careful review of the risks and benefits, in this instance, of nuclear power and nuclear wastes.

A critical part of this process is the recognition that no source of energy is risk free. To begin from the position that there must be zero risks, particularly in the area of nuclear power, will frustrate at the outset any meaningful dialogue about the development of nuclear power and important issues such as radiation protection criteria. More significantly, the long term result of this kind of emotionalism will be substantial harm to the public good.

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* Forbes, et al., The Nuclear Debate: A Call to Reason 2, Energy Research Group, Inc., Framingham, Mass., 1976, at 8-9.

† For example, one month's delay of a single 1,000 MWe nuclear station can lead to 38,000 equivalent person-days of illness if the replacement electricity is generated by oil and coal fired stations representative of current practice. Burnett, The Human Cost of Regulatory Delays, Westinghouse Electric Corporation, Pittsburgh, Pa., 1976, at 1. Environmental costs are even more significant. In one study dealing with the licensing of thirteen nuclear power stations, the Nuclear Regulatory Commission estimated that a one year delay in issuing them could result in 6 to 700 additional deaths from utilization of coal for makeup energy. See Impact of Later Reversing a Decision to Adopt or Not to Adopt an Interim Rule Permitting Construction or Operation of Nuclear Power Plants, Office of Nuclear Reactor Regulation, U.S. Nuclear Regulatory Commission, October, 1976, at 9.

In addition, assessments need to be made as to what would be the most beneficial approaches to be taken in dealing with the issues. These assessments must be squarely based on a broad understanding of the public interest and not upon undisclosed assumptions or prejudgments about the value of risks of nuclear power. Nor must they reflect the bias of any particular group or organization. Any such assumptions must be stated fully at the outset of workshops such as these and the basis for making such assumptions needs to be explained.

Finally, Pacific Legal Foundation believes that EPA should carefully review its statutory authority in this area to ensure that it is authorized to proceed and that such activities will not duplicate or be in conflict with the activities of other Federal agencies. Reorganization Plan No. 3 of 1970 transferred to EPA authority to establish "generally applicable environmental standards for the protection of the general environment from radioactive material." Yet the Energy Reorganization Act of 1974, 42 U.S.C. Section 5801, et seq. provided ERDA and NRC with authority to develop waste management programs designed to facilitate the safe disposal of radioactive wastes. Pursuant to this, both NRC and ERDA have been engaged in preparing detailed programs for the safe disposal of radioactive wastes.* These programs necessarily encompass environmental protection issues. As a result, the present proposal may well be in conflict with the purpose of the Energy Reorganization Act.

Furthermore, it should be noted that NRC prepares an environmental impact statement (EIS) in connection with each construction permit or operating license it issues. It has also prepared generic EISs dealing with the reprocessing and waste management portions of the nuclear fuel cycle for uranium-fueled reactors. The Energy Research and Development Administration is, moreover, presently in the process of preparing a draft generic EIS on its commercial nuclear waste management programs to be issued in the spring of 1977. Efforts by EPA at this time in light of the activities by NRC and ERDA would be a duplication by one Federal agency of the activities of others, and confuse the statutory mandates of these agencies.†

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* See, e.g., Environmental Survey of the Reprocessing and Waste Management Portions of the LWR Fuel Cycle, NUREG-0116, Office of Nuclear Material and Safeguards, U.S. Nuclear Regulatory Commission, Washington, D.C., 1976, Appendices B and C.

† See specifically 42 U.S.C. Section 5820.

STATEMENT OF MYRA CYPSER*

The nuclear waste isolation techniques, (a) isolation by permanent geologic storage and (b) isolation by disposal in geologic media, will require surveillance for as long as the wastes are environmentally hazardous. Surveillance is necessary because the waste repository must be protected against any human activities which could either directly or indirectly endanger the integrity of the containment site.

It cannot be assumed that people living hundreds or thousands of years from now will still know about the locations of our nuclear waste repositories or that they will have any knowledge of radiation physics and radioactive waste management techniques. It is possible that they could unknowingly cause serious damage to the integrity of a repository. Therefore, some system of surveillance would have to be implemented in order to protect the waste site and to prevent future generations from unknowingly harming their environment.

Currently, some radioactive wastes are disposed of in "burial grounds." Portions of these buried wastes contain long-lived plutonium and high activity fission products and consequently need to be completely contained. It is doubtful that these burial grounds can provide long-term containment for the wastes because they are subject to environmental surface phenomenon and are particularly subject to human activity. Because of the wastes' vulnerability to natural and human events, constant surveillance is necessary in order to ensure their containment. This surveillance will have to be provided for the lifetime of the wastes.

A plan for surveillance of the waste disposal or permanent waste storage site must be developed. The development of such a plan at this time is imperative, because it would be irresponsible to proceed with waste management plans without a provision for guarding the wastes from impacts caused by human activity.

This surveillance system would have to last for the lifetime of the wastes, hundreds of thousands of years, essentially a perpetual surveillance system. Because of the length of time involved, this surveillance system could not be dependent on human action for its continuation. For example, it could not be dependent on government management.

Because the human values, institutions, and technologies of the far future cannot be predicted with great accuracy, this

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* Office of Enforcement, Environmental Protection Agency (EPA).

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surveillance system could not be dependent on assumptions made about them. For example, it could not be dependent on the assumption that a particular waste site would be safe from disturbance by future generations because they would consider it worthless in terms of natural resources.

The implementation of a perpetual surveillance system may have an impact on our technology and social systems. There should be an analysis made of: (a) the monetary costs involved, (b) the magnitude and characteristics of social and institutional changes which would take place, and (c) the commitments of resources and the technologies needed to maintain surveillance for the lifetime of the wastes.

The environmental impacts of possible accidents, both natural and anthropogenic, which could affect the integrity of a waste repository should be investigated. Such accidents may include: sabotage, drilling or mining, attack by nuclear weapons, earthquakes, changes in climate, and changes in surface and sub-surface hydrology. The probability of such accidents occurring and the risk involved should be indicated. The calculations and assumptions used to determine probability and risk should be included in the criteria documents and not merely footnoted. In designing an environmental standard, EPA should also consider the maximum possible environmental impact which would result from the release of all the accumulated nuclear wastes (no matter what the mechanism of release).

In designing a standard for protecting the environment from the impact of radioactive wastes, EPA will have to consider how the standard will be enforced. Because of the long-lived nature of the wastes, it would be impossible to enforce a standard during the entire period the wastes are environmentally hazardous. Consequently, a standard will have to be developed which could ensure protection of the environment by being enforced over a reasonable time period.

In developing criteria, EPA should not only consider available information, but should also summarize all the areas of nuclear waste management where information is incomplete or missing, and where technologies and strategies are partially or totally undeveloped. Such areas might incude: (a) technology for sealing the access shafts to the respository after waste emplacement, (b) experimental data on sorption of specific radioactive nuclides in geologic media, (c) information on the thermal and radiation effects of emplaced wastes on surrounding rock formations, and (d) strategies for perpetual surveillance of the waste. A summary would provide an overview of the amount of uncertainty which would be inherent in the evaluation of potential environmental impacts.

STATEMENT OF W.L. BOECK

I think that the Environmental Protection Agency (EPA) should begin to develop criteria for protection of the inanimate environment. These criteria should respond to the hypothesis that an accumulation of atmospheric krypton-85 poses a risk of climate change. This krypton-85 risk hypothesis has been presented to a wide scientific audience through publication (Science 193:195-198). In my opinion, the present base of evidence for the krypton-85 risk hypothesis is comparable to a finding or "probable cause" in the legal sense. Such a finding moves the legal process from the Grand Jury proceeding to the pretrial and trial phase. The lack of published counterarguments to the krypton-85 hypothesis may either indicate an implicit judgment that cause exists for further investigation or simply lack of interest.

A regulatory response is necessary because the publication in Science clearly states that present criteria and standards will allow krypton-85 concentration at levels where a risk is hypothesized. An appropriate response would be to draft criteria and standards that would prevent any atmospheric effects of krypton-85 from becoming significant compared to the effects of natural background ionizing radiation. This would, in effect, establish a tolerance level for additional ionizing radiation in the atmospheric environment. Once a tentative tolerance level were proposed, interested parties could examine the economic or social costs to ensure that releases of radioactivity would not exceed the tolerance level. Once costs were estimated, there would appear three options: (1) Assume the cost of krypton-85 control to prevent the conditions necessary for any risk due to krypton-85; (2) make a quantitative assessment of the probability of the validity of the krypton-85 risk hypothesis and an estimate of the cost of social, environmental, and climatic consequences; or (3) allow krypton-85 concentrations to exceed the tolerance level and accept the risk of climatic change. The last option is nothing less than an experimental test of the krypton-85 hypothesis.

Any decision EPA makes to reduce the size of atmospheric releases of krypton-85 on the basis of biological criteria will increase the time available before the tolerance level is exceeded. A decision not to respond to the krypton-85 risk hypothesis could ultimately be identical to a conscious choice of the third option.

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CLOSING REMARKS

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First I want to thank all of you for your participation. At the outset of this Workshop, I stated that my intended purpose was to listen rather than talk myself. However, I found that very difficult because there were a lot of things I would have liked to remark on myself, but I suspect I will have ample opportunity in the future.

There were a number of things discussed at this meeting that should be addressed further in the Albuquerque Workshop, and I want all the people here to help us formulate the kinds of things we should cover. The only time I did speak up at this Workshop was in regard to definitions. In that instance, we were discussing what is meant by "zero release." I feel that at the Albuquerque Workshop there ought to be some discussion of definitions of terminologies. The EPA staff will address such definitions in an issue paper which will serve as a starting point. Hopefully, we will not have to re-invent the wheel for these.

The second thing that came up which I think is a topic for fair game is how do we present these highly technical matters to the public. There have to be ways of taking information and treating it not from the expert's point of view but from the point of view of the public, to say what is meaningful and what is not meaningful. I do not know how to do it. I do not think anybody knows how to do it well. But we certainly would like to learn.

Another thing that was not brought up but should be discussed is the philosophical question of what price should we pay for credibility. How far do we lean one way or the other to make sure that everybody thinks what we are doing is credible, if at all? At least that is one of the issues that I think has not yet been addressed, at least from the point of view of environmental standards. And, of course, there is the whole problem of these broad philosophical questions to which we will never find answers, but which still ought to be addressed as philosophical issues.

The most important thing which I think I want to point out is as we go forward to ask ourselves how we should set standards. We are trying to make this an open process from the very beginning. We are going to take the reports that came in today, and the next Workshop, and any other comments people have at any time during the process, and they will all be given due consideration as we develop these criteria. If we have strong suggestions or various suggestions made to us, we will attempt to put those into use. If we adopt some of them, we will say why. If we do not adopt them, we will also say why. The point is, this is not a sterile exercise. This is the kind of input that we are going to use in every issue that is brought up. We will have to consider, adopt, reject, modify, or do something with it, and explain why we have done it and how we have done it. I am not suggesting that every one of them will be accepted or every one of them will be rejected, but, nevertheless, we will give every one of them due consideration.

With that I want to express the fact that the Albuquerque Workshop will be held on the 12th, 13th, and 14th of April and is again going to be an open Workshop. I do not know what everybody is going to cover because it is the Workshop itself that will lead us to where we go, except that we will try to address some of these things in the issue papers. I invite all of you to attend if you can and to let people know about it. I hope at the next Workshop we will not be duplicating what we have done here particularly but will go on to new things.

With that I want to thank all of you for your participation and hard work. Thanks very much.

APPENDIX A*

HIGH-LEVEL, LONG-LIVED RADIOACTIVE WASTES: CONCEPTS AND COMPARISONS

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* Materials presented in this Appendix were produced through consultation with Dr. Keitn Schiager, University of Pittsburgh, for the U.S.E.P.A.

SOURCES

Three major categories of radioactive wastes that exist in the United States at the present time are compared:

1. Fission products generated by chemical processing of nuclear reactor fuel to extract plutonium for nuclear weapons for the national defense program. (These are generally referred to as high-level defense wastes.)

2. Transuranic nuclides (man-made nuclides heavier than uranium-238) that remain in the high-level wastes, including the unextracted fraction of the plutonium.

3. Natural radioactivity contained in wastes from mining and milling of uranium and phosphate ores.

These three categories were selected for comparison because they represent both the high-level and long-lived radioactive wastes that are of primary concern to many individuals. The sources and forms of these wastes are described and compared in order to emphasize elementary concepts that must be considered in radioactive waste management and disposal.

The comparisons have been simplified by considering, within each category, only the most critical nuclides, i.e., those that contribute or control essentially all of the potential radiation dose to humans. In the fission product category, only strontium-90 and cesium-137 are included; other products are of much lesser significance, either because of their much shorter half-lives or because of the much smaller activities and/or relative hazards.

The transuranics considered in these comparisons are the plutonium nuclides 238, 239, and 241, and americium-241. Of the naturally occurring radionuclides, only thorium-230 and radium-226 are included in the comparisons. This was done simply because the only condition used for comparison of relative risk was the dissolution of waste nuclides in water. The comparisons do not include external irradiation or inhalation of airborne radionuclides that would result from the radionuclides following radium in the uranium decay series, as would occur if these wastes were left exposed on the earth's surface.

High-level radioactive wastes are presently stored at the three major Energy Research and Development Administration (ERDA) laboratories: Hanford Reservation in Richland, Washington; Savannah River Plant in Aiken, South Carolina; and Idaho National Engineering Laboratory in Idaho Falls,

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Idaho.* The high-level waste is stored in various forms of solids (salt cake, sludge, calcined solids), and in liquid awaiting calcination or in the process of self-concentration by evaporation due to decay heat (Refs. 1-3). The wastes from uranium and phosphate mining are located near the mining and milling sites. These sites are primarily in Florida for phosphates and in the western states for uranium (Refs. 4-6).

In the following sections, the volumes and activities of the wastes currently in storage are summarized. Materials not presently classified as wastes are not included even though they may fall into the same categories. For example, fission products and transuranics contained in unreprocessed reactor fuel elements are not included, nor are the large quantities of depleted uranium currently stored at enrichment facilities. Inclusion of these additional sources would change specific numerical values, but would not significantly change the general concepts addressed in the following sections. In particular, the relative hazard comparison, presented in the final section, would remain essentially the same.

VOLUMES

The current total volumes of radioactive waste from the three sources under consideration are depicted in Figure 1 (Refs. 1-6). For purposes of comparison, all volumes are expressed in gallons even though all wastes are not in liquid form. The processes that generate the wastes are summarized for each of the major sources in the following sections.

PHOSPHATE INDUSTRY

Wastes from the phosphate industry are generated during several different steps of the production process as shown in Figure 2. The greatest quantities of wastes are generated during beneficiation and are in the form of sand tailings and slimes. Lesser amounts of gypsum from the production of fertilizers and electric furnace wastes (mostly slag) from the production of elemental phosphorus are also produced. The total volume of all wastes from the phosphate industry is nearly as large as the initial volume of the phosphate ore mined and is estimated to be approximately 4.4×10^{11} gallons. This volume would cover Washington, D.C., to a depth of 35 ft.

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*Waste from commercial reprocessing of reactor fuel consists of 0.6 million gallons contained in one tank at Nuclear Fuel Services, Inc., West Valley, New York. This is less than 1 percent of the total defense wastes and is not included in this evaluation.

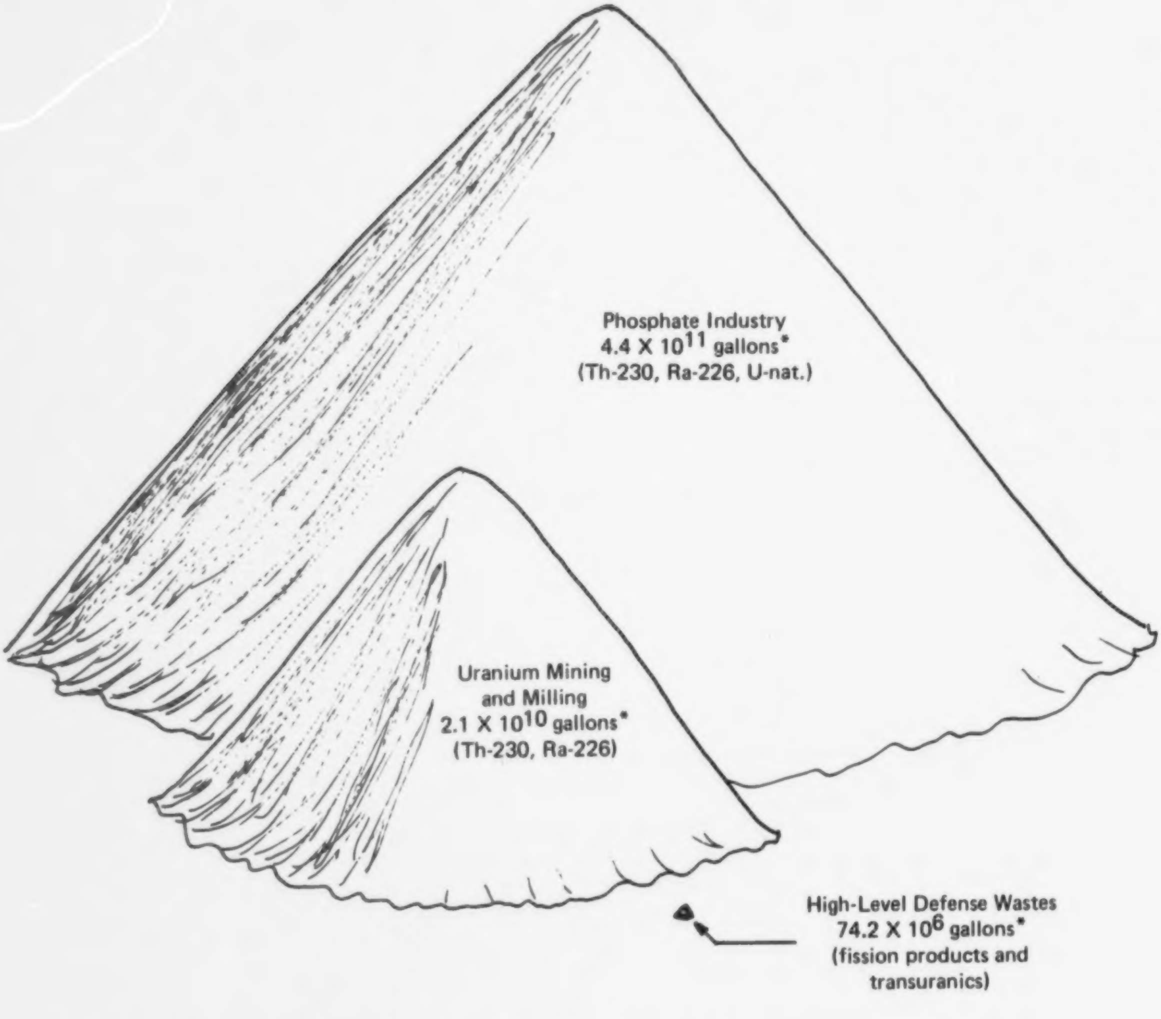
Phosphate Industry
4.4 X 10¹¹ gallons*
(Th-230, Ra-226, U-nat.)
Uranium Mining
and Milling
2.1 X 10¹⁰ gallons*
(Th-230, Ra-226)
High-Level Defense Wastes
74.2 X 10⁶ gallons*
(fission products and
transuranics)

Figure 1. Volumes of radioactive wastes. *All numerical values contained in this summary represent the best approximation that could be derived from the referenced materials. The uncertainty associated with some of the values, however, may be as large as ± 25%.

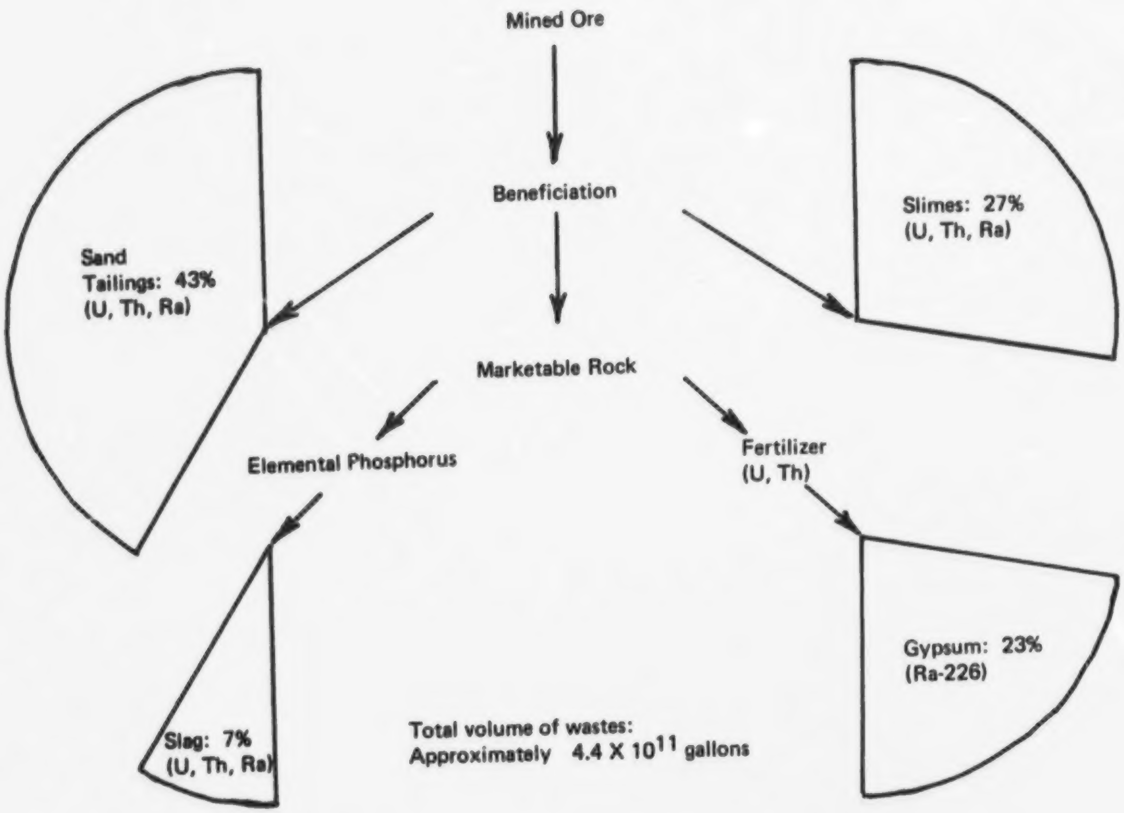
Mined Ore
Beneficiation
Sand Tailings: 43% (U, Th, Ra)
Slimes: 27% (U, Th, Ra)
Marketable Rock
Elemental Phosphorus
Fertilizer (U, Th)
Slag: 7% (U, Th, Ra)
Gypsum: 23% (Ra-226)
Total volume of wastes: Approximately 4.4 X 10^11 gallons

Figure 2. Sources and relative volumes of phosphate industry wastes.

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The significant radionuclides in these wastes (U-natural, Th-230, and Ra-226) are distributed among the sand tailings, slimes, and slag in approximately the same proportions and concentrations as found in the original ore. (If secular equilibrium exists in the ore, then the activities of U-238, Th-230, and Ra-226 would be approximately equal in three of the four waste fractions.)

In the wet chemical processes used for making phosphate fertilizers, some fractionation of the radioactivity occurs, with the result that uranium and thorium tend to stay in the fertilizer and radium is preferentially rejected to the gypsum waste. Reduced concentrations of uranium and thorium are also found in the gypsum, however, since the separation is not complete.

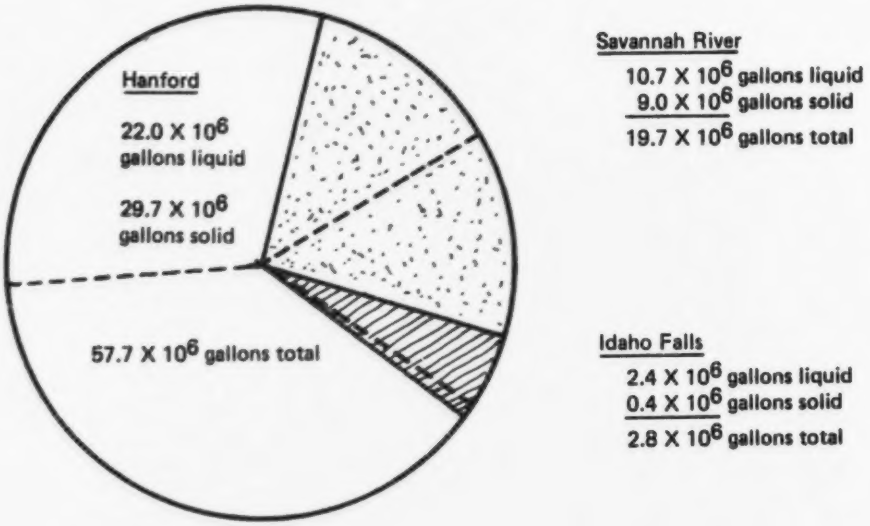
URANIUM MINING AND MILLING

The radioactive wastes from the uranium mining industry are predominantly in the form of mill tailings. After extraction of the uranium, the principal radionuclides in the tailings are Th-230 and Ra-226, which are nearly in equilibrium. The tailings consist of two fractions: slimes containing a large portion of the radioactivity and sand tailings comprising most of the volume. However, these fractions are not necessarily separated during the milling process and may simply be mixed together for disposal. The volume of the tailings is about the same as the total volume of ore mined because the uranium content of the ore is a very small percentage. The total current volume of tailings, at both active and inactive mill sites, is assumed to be equal to the total volume of ore mined to date, or approximately 2.1×10^{10} gallons (Ref. 4). This is approximately the volume of the Empire State Building.

HIGH-LEVEL DEFENSE WASTES

The high-level defense wastes are produced and stored at the three ERDA production facilities previously identified (Hanford, Savannah River, and Idaho Falls). The high-level wastes may be in liquid or in one of three solid forms containing fission products and transuranic nuclides. Figure 3 illustrates the distribution of the high-level wastes among the three locations and the liquid and solid forms (Refs. 1-3, 7). The total volume of the high-level defense wastes is approximately 74.2×10^6 gallons, which is roughly equivalent to the capacity of an oil supertanker.

All of the high-level wastes are initially generated as liquids. At Hanford and Savannah River the solid wastes are in the form of sludge and salt cake. The sludge is precipitated out of the liquid, and the salt cake results from partial evaporation of the liquid. This process results in about a 3.5-to-1 volume reduction from liquid to solid.



High-level waste total volume: 74.2 X 10^6 gallons

Figure 3. Distribution of high-level defense waste of volumes.

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Both the sludge and the salt cake are relatively soluble. The major nuclide in the sludge is Sr-90, while in the salt cake the major nuclide is Cs-137. Some of the liquid waste at Hanford has been reprocessed to remove Sr-90 and Cs-137. The extracted nuclides are metallized and doubly encapsulated and are not, thereafter, included in the "waste" inventory. To date, approximately 22 percent of the Sr-90 and Cs-137 activities have been removed from liquid waste inventories by this method.

At Idaho Falls, the solid wastes are calcined from the liquid. Calcination results in about an 8-to-1 volume reduction. These calcined solids are less soluble than the other solids (Ref. 13). There is no separation of radioisotopes in the calcination. Due to the various solidification processes employed, the remaining liquid wastes contain varying amounts of Cs-137 and Sr-90.

ACTIVITY

The activities of the radionuclides of interest are listed in Table 1. The activities were derived from the summation of the waste inventories at the three ERDA facilities and for the entire uranium and phosphate mining industries (Refs. 1-7). All activities listed have been corrected for decay through 1976. The activities of Sr-90 and Cs-137 shown in Table 1 were derived from an inferred Cs:Sr activity radio of 3:2 (Refs. 1-3). The activity estimates for the individual transuranic nuclides were made by applying the isotopic ratios of the spent fuels at Hanford and Savannah River to the proportionate fractions of the total mass of 625 kg of plutonium waste. Although the total mass of plutonium waste is known to within ±25 percent (Ref. 1), the uncertainties in the estimates of individual activities of the transuranic nuclides are somewhat greater.

In order to illustrate the changing nature of radioactive wastes, the activities remaining after 500 years are also included in Table 1. In that period of time, the activities of Sr-90 and Cs-137 will decrease by more than 100,000 times. Plutonium-238, the major constitutent of the transuranic waste today, will decrease in 500 years to less than 2 percent of its present activity. Plutonium-241 will disappear in 500 years, but since it decays to Am-241, it will add a small amount to the americium inventory (Figure 4).

The waste activities of the uranium and phosphate mining and milling industries are comparable to each other, both at the present and also after any decay period. The relative activities of all of the wastes are illustrated in Figure 5.

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Table 1 Radioactivity Content of Existing Wastes(a)

Origin High-Level	Nuclides	Isotopic Activity (Ci)			
		Present		500 Years in Future	
Fission products	Sr-90	1.8×10^8	4.4×10^8	1.1×10^3	3.8×10^3
	Cs-137	2.6×10^8		2.7×10^3	
Trans-uranics	Pu-238	1.0×10^6	1.3×10^6	1.8×10^4	1.5×10^5
	Pu-239	3.3×10^4		3.3×10^4	
	Pu-241	1.8×10^5		--	
	Am-241	1.0×10^5		1.1×10^5	
Phosphate mining	Ra-226	7.9×10^4	2.2×10^5		2.2×10^5
	U-nat	6.8×10^4			
	Th-230	6.9×10^4			
Uranium mining	Ra-226	7.1×10^4	1.4×10^5		1.4×10^5
	Th-230	7.1×10^4			
	Total Activity		4.4×10^8		5.2×10^5

(a) Source: Refs. 1-7.

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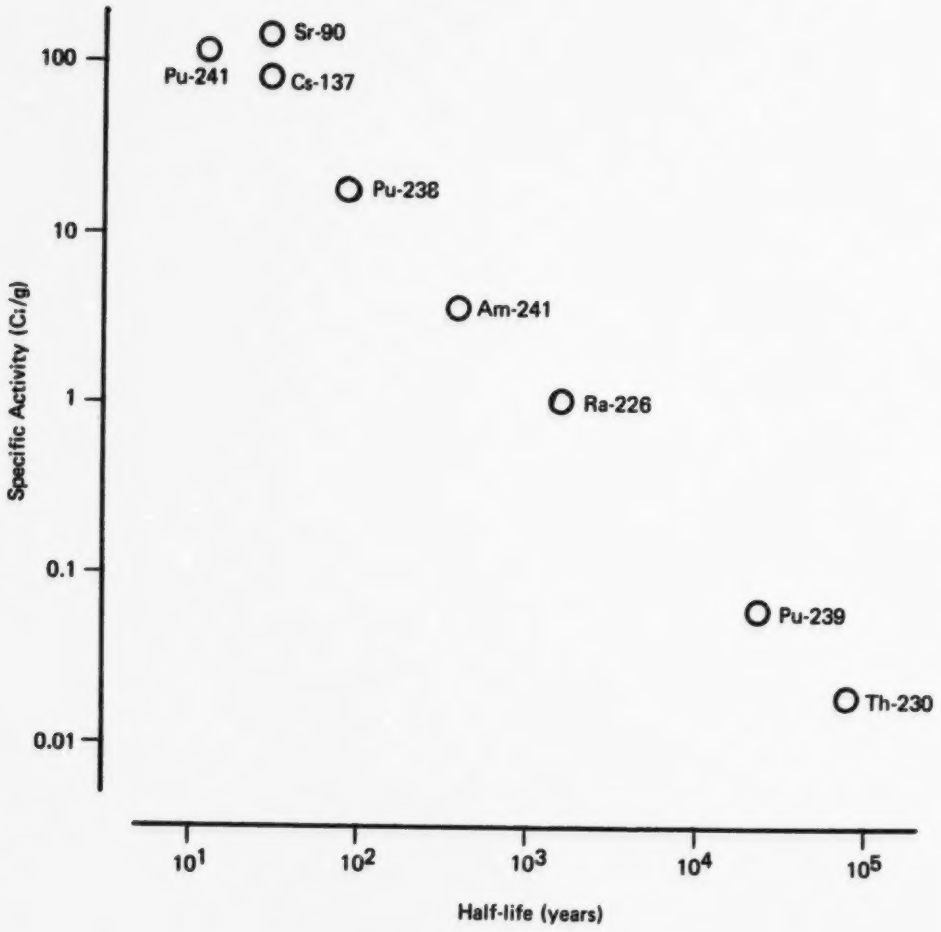

Figure 4. Specific activity versus half-life.

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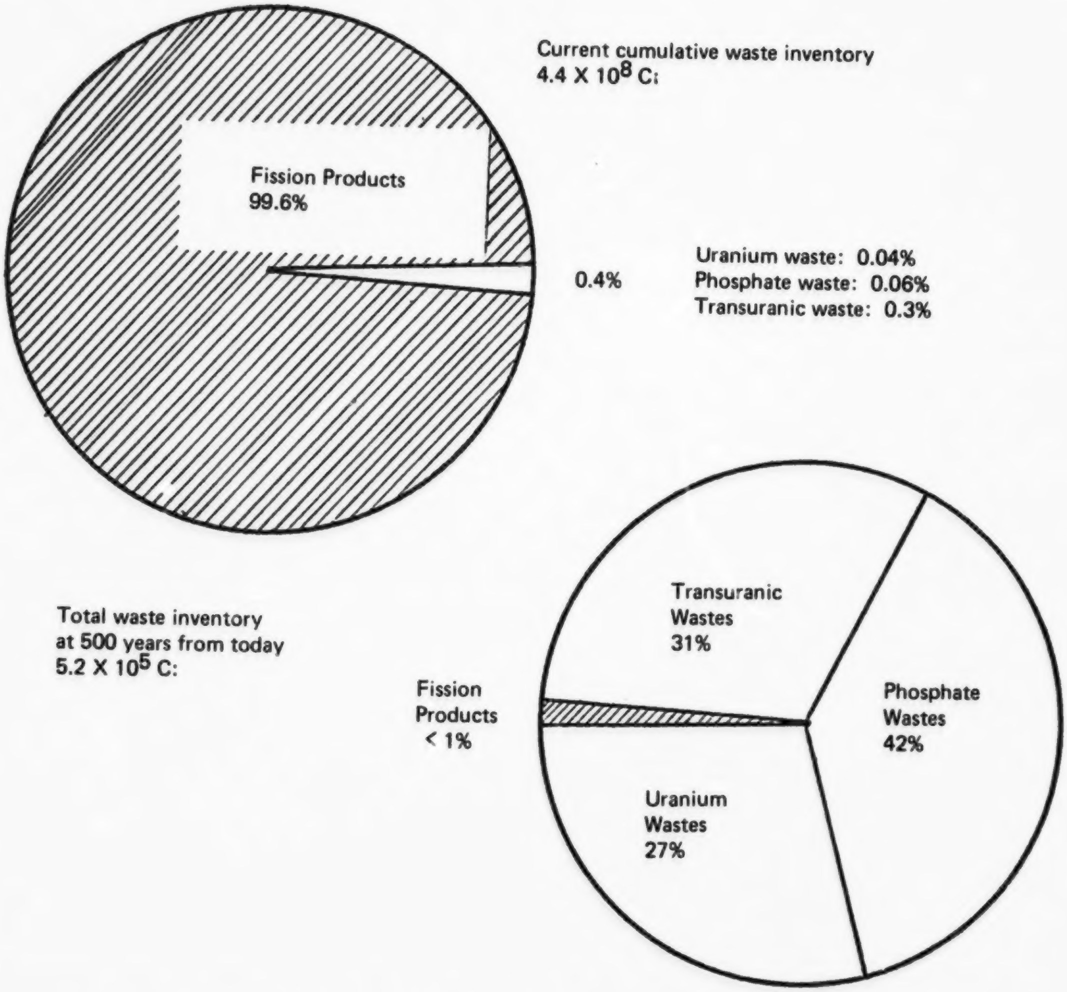

Figure 5. Percentage activities of current waste inventories at present and after 500 years.

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RELATIVE HAZARD INDEX

In order to compare the radiation hazards that may be represented by the various categories of radioactive wastes, a single index of hazard is desirable for simplification (Ref. 10). The index selected for this analysis is the volume of water that would be needed to dilute all of the radioactivity in the wastes to the concentration limit for continuous exposure of the general public, as specified in 10 CFR 20 (Ref. 11). Thus, a relative hazard index (RHI) is defined as the total activity of a particular constituent of the radioactive waste inventory divided by the radioactivity concentration guide (RCG) for that constitutent in water. The values of the RHI (in gallons) for current inventories of radioactive wastes, and for the same wastes at a time 500 years in the future, are shown in Table 2 and Figure 6.

The short-lived high-level wastes, primarily Sr-90 and Cs-137, require the most dilution today, with Sr-90 being the primary hazard. They require much more dilution than the long-lived high-level wastes Pu-239 and Am-241. For comparison, the water needed to dilute present mine wastes is about one half the volume of Lake Superior. In 500 years the situation changes dramatically. Cesium-137 and Sr-90 have decayed to a very small fraction of the total hazard, with the hazard from the other nuclides essentially unchanged. The greatest relative hazard is then uranium and phosphate wastes, over both fission products and transuranic wastes.

GENERAL CONCEPTS

1. In recently separated reactor wastes the radiation hazard from fission products will be orders of magnitude greater than that from transuranic nuclides.

2. Within a few centuries after the production of reactor wastes, the fission products will have decayed to the point that their contribution to the total radiation hazard is a very small fraction of the total.

3. In terms of total radioactivity potentially available to the biosphere, the corresponding relative hazard index, the wastes from mining and milling of radioactive ores are of far greater significance than the transuranic nuclides produced in nuclear reactors.

4. If the linear, nonthreshold model of radiation effects is assumed to be correct, the cumulative radiation dose potentially available to the total population (represented by the RHI) is a valid measure of the relative toxicity and risk associated with each category of radioactive waste. The particular distribution of the waste materials and specific modes of entry into the biosphere would be of lesser importance.

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Table 2 Relative Hazard Index (RHI) for Current Inventories of Radioactive Wastes

Nuclide	RCG (Ci/gallon)	Present Activity (Ci)	Relative Hazard Index (gallons)
Sr-90	1.1×10^{-9}	1.8×10^{8}	1.6×10^{17}
Cs-137	7.6×10^{-8}	2.6×10^{8}	3.4×10^{15}
Pu-238	1.9×10^{-8}	1.0×10^{6}	5.3×10^{13}
Pu-239	1.9×10^{-8}	3.6×10^{4}	1.9×10^{12}
Pu-241	1.1×10^{-6}	2.3×10^{5}	2.1×10^{11}
Am-241	1.5×10^{-8}	1.0×10^{5}	6.6×10^{12}
Ra-226	1.1×10^{-10}	7.1×10^{4} (a) 7.9×10^{4} (b)	6.3×10^{14} 7.0×10^{14}
Th-230	7.6×10^{-9}	7.1×10^{4} (a) 6.9×10^{4} (b)	9.4×10^{12} 9.1×10^{12}
U-natural	1.1×10^{-7}	6.8×10^{4}	5.9×10^{11}

(a) Uranium.
(b) Phosphate.

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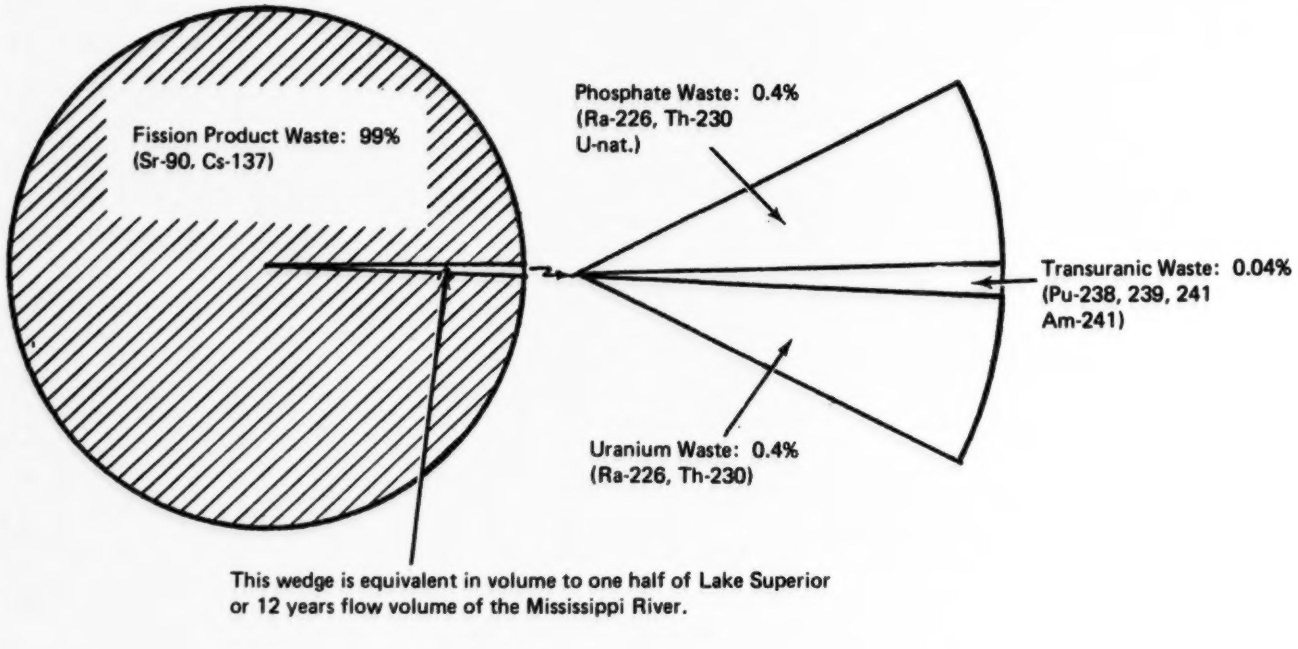
CURRENT WASTE INVENTORY



CURRENT WASTES AFTER 500 YEARS

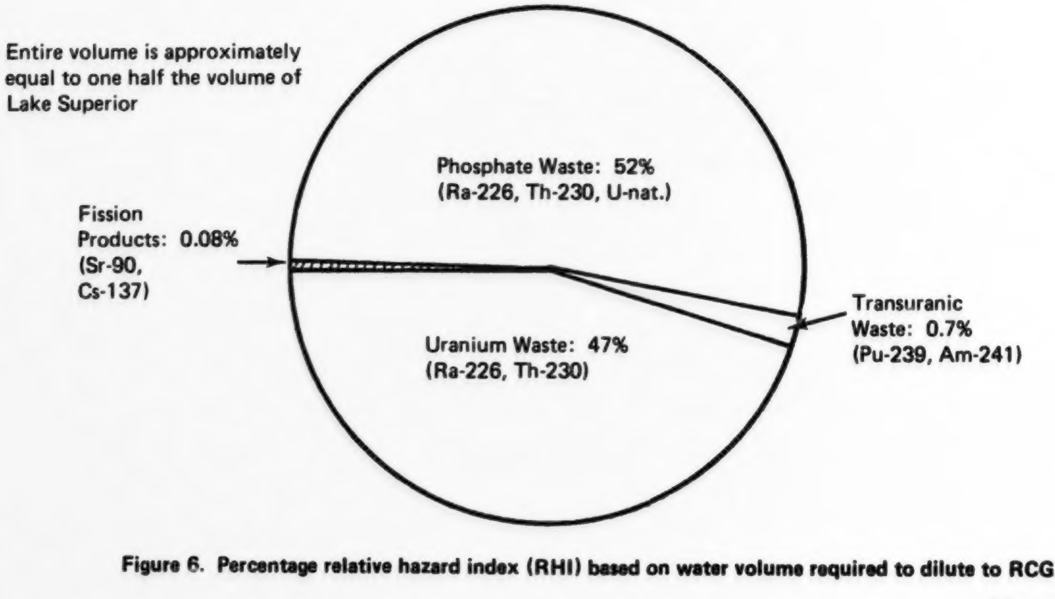


Figure 6. Percentage relative hazard index (RHI) based on water volume required to dilute to RCG.

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GLOSSARY

Activity - A measure of the rate at which nuclear disintegrations occur, usually expressed in curies (Ci).

Beneficiation - A process that increases the concentration of a desired mineral in an ore.

Calcination - Solidification method for disposal of liquid wastes involving atomizing and coating of liquid on small granular solids and heating to drive off moisture.

Concentration - The activity per unit volume of any material.

Curie (Ci) - The basic unit of radioactivity of a material. One curie is approximately 37 billion disintegrations per second or approximately the radioactivity of 1 g of radium.

Decay - The spontaneous radioactive transformation of one nuclide into another.

Half-life - The time in which half the atoms in a radioactive substance disintegrate.

High-level wastes (as used by ERDA) - Wastes from the operation of the first cycle extraction system consisting of essentially all of the nonvolatile fission products, small amounts of uranium and plutonium, and other heavy elements.

Nuclide - Any atomic nucleus specified by its atomic weight, atomic number, and energy state.

Radioactivity - The spontaneous decay or disintegration of unstable atomic nuclei accompanied by the emission of radiation.

Radioactivity concentration guide (RCG) - The maximum concentration of radioactive materials in air or water to which an individual may be continuously exposed without exceeding an established dose limit.

Specific activity - The activity per gram of a nuclide, an element, or of a chemical compound.

Tailings - The portion of ore remaining after a mineral has been extracted.

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APPENDIX B

ATTENDEES AT THE RESTON WORKSHOP

Dr. Achilles Adamantiades
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McGraw-Hill Publishing Co.

Jeanne Agee
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Steve Andersen
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Harold Bernard
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